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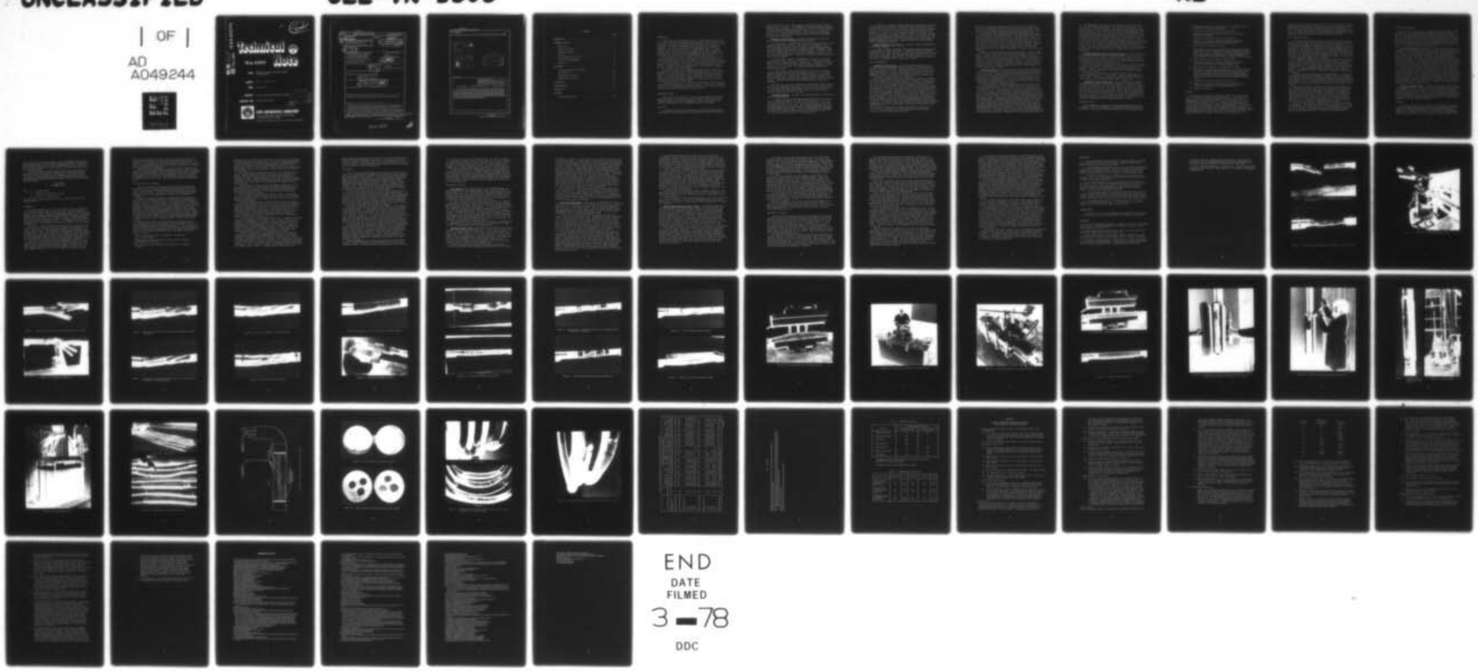

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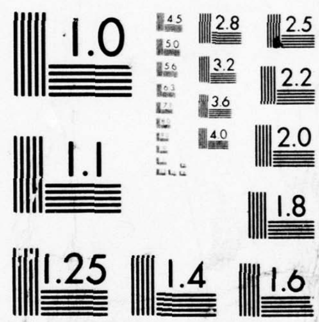

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1. Shrinkable tubing 2. Splicing THOF-400 power cable I. YF53.534.006.01.032

The splicing of THOF-400 flexible shore-to-ship power cable with shrinkable tubing was investigated, and the spliced cables were subjected to flexing, water immersion heat cycling, and abrasion. The conductors were spliced with compression fittings, and these were insulated with heat-shrinkable tubing splices. Splice covers made with large heat-shrinkable polyolefin tubing gave satisfactory performance, but properly prepared vulcanized neoprene splice covers gave better performance. An ambient-temperature-cured polyurethane material showed promise as a splice cover but has not been sufficiently developed for this use.

CONTENTS

INTRODUCTION

Flexible shore-to-ship cables are used to supply power to cold iron ships, which have shut down their own power plants. Such cables are used at many Navy activities, including Naval stations, Naval air stations, and shipyards. The power is generally supplied at 480 V, three-phase, ungrounded. An effort is being made to standardize the use of three-conductor, heat- and oil-resistant, flexible (THOF) cable. For 400-A service, three conductors with cross sections of 400,000 circular mils (400 MCM) (2.03 sq cm) have been used (THOF-400), but more recently the larger 500 MCM (2.53 sq cm) cable (THOF-500) has been specified.

The shore-to-ship cable is often slung low from the dock, over the intervening saltwater, and up to the deck of the ship; and cable with faulty insulation poses an electrical hazard. When such cable is repaired it often must be spliced. Splices are also used to connect cables to the pigtails of large plugs or to permanently join together shorter pieces of cable. Because this large copper cabie is very expensive, salvaging of shorter lengths is often worthwhile.

In earlier studies [1] shrinkable tubing was found to be a useful material for covering splices on underground distribution cables. Similar shrinkable tubing can be used to cover the spliced conductors of THOF cables, and larger shrinkable tubing is available as an outer sleeve to replace the outer cable jacket. Splices with these splice covers were studied at the Civil Engineering Laboratory (CEL), and the results are presented and discussed in this report.

In addition to the splices covered with shrinkable tubing, two other types were investigated and the results reported: splices with shrinkable inner sleeves but vulcanized outer splice covers and splices with ambient-temperature-cured polyurethane outer splice covers.

EXPERIMENTAL WORK

This portion of the report is a detailed description of the experimental work and of the observed results. A general discussion of the available splice covers, the test methods, and the significance of the results is contained in the "DISCUSSION" portion of the report.

Materials

Six different splices were prepared with the splice covers listed below and were tested in duplicate. The splices were made with THOF-400

cable from Navy stock [2]. This neoprene-covered cable had a diameter of about 2.8 in. (7.1 cm). The 400-MCM (2.03 sq cm), 2052-strand copper conductors had a diameter of about 0.823 in. (2.09 cm) and were connected with 500 MCM copper compression sleeves 2-7/8 in. (7.3 cm) long and 1-1/16 in. (2.7 cm) OD (Burndy YS34L). These sleeves were compressed with dies and a hydraulic tool providing about 12 tn of force (Burndy U34RT dies and Y35 Hypress).

Shrinkable Tubing Splices. Shrinkable tubing splices were made with products from the following three manufacturers.

A. Outer sleeve: Sigmaform SFMT 36-40 with standard sealant. This Sigmaform tubing, mine type, is 4 in. (10.16 cm) in diameter, 36 in. (91.4 cm) long, and made of "Flex 6" material (essentially the same as the tubing approved by the Bureau of Mines and marked P-156-BM). Inner sleeves: Sigmaform SFMT 24-15 with standard sealant. From this tubing, 24 in. (61 cm) long and 1.5 in. (3.8 cm) in diameter, sections 7 in. (17.8 cm) long were prepared. (Sigmaform Corporation, 2401 Walsh Avenue, Santa Clara, CA 95050).

B. Outer sleeve: ECC No. 8 DURA-SPLICE, 36 in. (91.4 cm) long. This tubing is 3.9 in. (9.9 cm) in diameter, is coated with a hot-melt adhesive, and is labeled P-154-BM. Inner sleeves: Insultite No. 256071, 1.5-in. (3.2-cm), 8 in. (20.3 cm) long, with hot-melt adhesive. These were cut to 7 in. (17.8 cm). (Electronized Chemicals Corporation, Burlington, MA 01803).

C. Outer sleeve: Raychem 205A440-4/42. This 4-in. (10.2-cm) diameter tubing with S-1017 hot-melt adhesive was 28 in. (71 cm) long (nominally 30 in. (76 cm) long) and labeled P-137-BM. Inner sleeves: Raychem WCSF-500-12-A. These 1.5-in. (3.8-cm) diameter sleeves, 12 in. (30.5 cm) long, with S-1017 hot-melt adhesive were cut to 7-in. (17.8-cm) lengths. (Raychem Corporation, 300 Constitution Drive, Menlo Park, CA 94025.)

The filler for one set of three splices was AMP No. 602213-1 sealer and dielectric compound, which was 1/8 in. (0.32 cm) thick and 3-3/4 in. (9.5 cm) wide (AMP Special Industries). The filler for the second set of three splices was Raychem No. S-1031 dielectric filler, 1/8 in. (0.32 cm) thick and 2 in. (5.1 cm) wide.

Vulcanized Splices. Two types of vulcanized splices were made with the following materials:

D. Dixon: This splice was made by personnel of the *U.S.S. Dixon* with a Joy Manufacturing Co. No. X8756 bench vulcanizer. The 25-in. (63.5 cm) mold had a 3.5-in. (8.9-cm) mold cavity 20 in. (51 cm) long and made by the crew of the *Dixon*. The vulcanizing material was Voit No. 03294 sheetstock (tread repair gum). The bonding agent was Joy No. 319,756 "Googum" rubber cement. (The Joy Manufacturing Co. recommends No. 319,757-1 unvulcanized neoprene for the vulcanizing material and No. 319,763-2 neoprene cement for the bonding agent.)

E. Hotsplicer: Hotsplicer Model 560J heavy duty molding press with splicing mold No. 24-325-287. The mold has an overall length of 24 in. (61 cm); the cavity has an 18-in. (46-cm) central portion with a diameter of 3.25 in. (8.3 cm), and it tapers to 2-in. (5-cm) end portions with diameters of 2.87 in. (7.3 cm). Raychem WCSF-500-12-A sleeves, cut to 6 in. (15.3 cm), were used as inner sleeves. About 5 lb (2.3 kg) of Hexcel No. 102 unvulcanized green neoprene tape was used. In addition, No. 601 neoprene bonding agent, No. 203 grey transitape, and No. 225 reinforced neoprene binding tape were used. (Hexcel Corporation, 20701 Nordhoff Street, Chatsworth, CA 91311.)

Ambient-Temperature-Cured Splice. One type of ambient-temperature-cured splice was made:

F. PRC: PR 498-1/4 three-part polyurethane insulating compound in 1/10-gal (380-ml) Semkit cartridges. A polyethylene mold with inside diameter of 3.5 in. (8.9 cm) and 26 in. (66 cm) long was used and required eight Semkit cartridges. The Raychem WCSF-500-12-A sleeves, cut to 7 in. (17.8 cm), were used as inner sleeves. (Products Research and Chemical Corporation, 2919 Empire Avenue, Burbank, CA 91505.)

Splice Preparation*

Shrinkable Tubing Splices. For the shrinkable tubing splices, a 7-ft and an 11-1/2-ft piece of THOF-400 cable were spliced together to provide a splice with an 18-in. open area between the cut ends of the outer cable jackets. The 3-in. compression sleeve connecting the white insulated conductor was placed in the middle of this area. The 3-in. compression sleeves of the red and the black insulated conductors were 1-in. from and to either side of this connector.

Preparation of these splices is illustrated in Figures 1 through 13. To obtain a tight splice and to maintain the conductors in their proper lay, all dimensions were carefully measured. The three conductors were cut to 13, 9, and 5 in. beyond the cable jacket, as shown in Figure 1. The cables were then assembled with the uncompressed connectors in place, and these were marked for their proper contact with the conductor insulation (Figure 2). A sleeve was compressed onto the shortest conductor of one cable with the manual compression tool, which was mounted on a jack for ease in maneuverability (Figure 3). A compression sleeve was attached to the short conductor of the other cable and to one of the white conductors (Figure 4). The inner shrinkable tubing pieces were inserted on the three longest conductors, and the compressions were completed so as to line up the connectors with the corresponding markings on the insulation (Figure 5). At the ends of the cable jackets, wire mesh electrodes were installed for electrical testing only, and these were connected to each

* For the splice preparations, lengths were measured in inches and feet. If S.I. units were to be used, adjustments would probably be made to obtain easily measured values.

other and to the center compression sleeve on the white insulated conductor; the shrinkable sleeves were then heated with an electric heat gun, first in the center and then toward the ends to shrink the sleeve and to melt and slightly extrude the adhesive liner (Figure 6).

The splice was then filled with dielectric compound, using either the AMP material or the Raychem material. The application of the latter material is shown in Figures 7, 8, and 9. Because 18-in. sections of this material were not available to cover the 18-in. space in the splice area, three sets of three 12-in. and 6-in. sections were used. The first set was tightly rolled and placed between the conductors, and this was covered by a second set that was folded in half. Finally, another set was used to cover the remaining exposed places, and additional material was placed at each end of the splice to build it up to the cable diameter.

The splice was then wrapped with varnished cambric, leaving exposed at each end some of the wire mesh electrode connected to the white insulted conductor (Figure 10). The other heat-shrinkable sleeve was placed over the spliced area and was heated with a propane torch (Raychem FH2605). A deflector was used, as shown in Figure 11, to spread the flame and to curl it around the shrinkable sleeve. The sleeve was first shrunk in the middle (Figure 12) and then carefully and slowly heated at each end until the tubing shrank down tight and a small amount of the adhesive was extruded (Figure 13).

Vulcanized Splices. For the vulcanized splice prepared aboard the *U.S.S. Dixon*, the portion preceding the vulcanizing step was performed at CEL to provide a splice essentially as shown in Figure 6, except that the shrinkable sleeves were unlined sleeves provided by Dixon. The splices were completed aboard the *U.S.S. Dixon* by ship personnel. The cable jacket was roughened with a file, and the whole splice was precoated with the bonding agent. The splice was wrapped with the vulcanizing material and was vulcanized at 325F.

For the Hotsplicer vulcanized neoprene splice, the inner portion was prepared essentially as before (Figure 6) except that the splice area was reduced from 18 in. to 16 in. by placing the connectors 1/2 in. — instead of 1 in. — apart from each other and by placing them closer to the cable jacket. The insulation on either side of each of the three pieces of inner shrinkable tubing was coated with bonding agent; and the ends of the outer jacket, after cleaning with trichloroethane and buffing with aloxite cloth to remove all shiny surfaces, were also coated with the bonding agent. The adhesive that had extruded from the inner shrinkable sleeves was then covered with gray transitape (Figure 14). Into the spaces between the inner conductors were placed several strips of the unvulcanized green neoprene, and these were held in place with the reinforced nylon binding tape (Figure 15). The splice area between the braided conductors was then covered with the reinforced nylon binding tape (Figure 16). The whole splice area was then covered with sufficient unvulcanized green neoprene to completely fill the mold area (Figure 17).

The wrapped splice was placed into the press which had been preheated to 225F (107C) (Figure 18). The press was closed most of the way, and 250 lb (113 kg) of tension was applied with the tension anchors shown in Figure 19. The eyebolt on the right had strain gages attached to determine the tension. The molds were firmly screwed together; and additional neoprene, which had been inserted into the transfer pot, was transferred into the mold (Figure 19) until the excess came out through the bleed holes on the top platen (Figure 20). The bleed holes were closed, the transfer pot removed, and the temperature raised to and held at 325F (163C) for 70 min. The press was allowed to cool to approximately 150F (66C), or was reheated to approximately this temperature after cooling overnight. The press was then opened (Figure 21) and the splice removed. The flashing at the body of the splice and the uncured neoprene at the ends of the splice were removed to produce the finished splice (Figure 22).

Ambient-Temperature-Cured Polyurethane Splice. For the preparation of the ambient-temperature-cured polyurethane splice, the cable was hung vertically and kept in tension by a 250-lb (113-kg) weight attached below the splice area. After the ends of the cable jacket were cleaned and abraded with a high speed rotary file, the polyethylene mold shown in Figure 23 was attached to the splice area.

The Semkit cartridges were mixed by removing the tape at the center, crushing a foil barrier, and then moving the plunger up and down for 60 strokes. The narrow rod shown in Figure 23 was then placed into the plunger to inject a catalyst, and the mixture was again mixed rapidly for at least 30 strokes.

The contents of the Semkit cartridge were then injected into the mold as shown in Figure 24. Eight Semkit cartridges were required to fill the mold. The next day the mold was removed, and the flashing was cut off the splice to give the finished splice (Figure 25).

Completion of Cable Preparation. Cable breakout boots (Sigmaform TH 250-500) were placed at each end of the spliced cables by cutting back the cable jacket so that the boots would be 5 ft from the center of the splice on the short end of the cable and 9-1/2 ft from the center of the splice at the long end of the cable. Before the boots were shrunk on, the conductors were covered with red, white, and black insulating tape for protection and identification. The individual conductors were cut off 6 ft and 10-1/2 ft from the splice centers, respectively. At the white conductor on the long end of the cable, a lug was attached for electrical measurements and for identification of the cable.

Sequence of Tests

The following is a sequence of tests and measurements that were performed. Some of the experimental procedures are later described in more detail. Each spliced cable was subjected to the following tests:

1. Immersion overnight in 3 ft (91 cm) of 3% saltwater, followed by insulation resistance measurement.
2. Flexing 100 cycles with 250-lb (113-kg) weight.
3. Immersion in saltwater overnight followed by insulation resistance measurement.
4. Flexing 200 cycles with 250-lb (113-kg) weight.
5. Immersion in saltwater overnight followed by insulation resistance measurement and voltage withstand test.
6. Heat cycling in saltwater for 5 days.
7. Measurement of insulation resistance after the first and third day of heat cycling, insulation resistance measurement of the cables in hot water at the end of the fifth heating period, and insulation-resistance measurement and voltage-withstand test after completion of the five cycles, including overnight cooling.
8. Flexing 200 cycles with 500-lb (227-kg) weight.
9. Immersion in saltwater overnight followed by insulation-resistance measurement and voltage-withstand test.
10. Heat cycling in saltwater for an additional 5 days.
11. Measurement of insulation resistance after the first and third day of heat cycling, insulation-resistance measurement of the cables in hot water at the end of the fifth heating period, and insulation-resistance measurement and voltage-withstand test after completion of the five cycles, including overnight cooling.
12. Flexing 200 cycles with 500-lb (227 kg) weight.
13. Immersion in saltwater overnight followed by insulation-resistance measurement and voltage-withstand test.
14. Abrasion resistance.

Flexing

The splices were flexed by pulling the cable over a wooden reel with a 32-in. (81-cm) core, as shown in Figure 26. The reel was held down by its support stand and by weights. Two cables were flexed simultaneously. The short ends of the cables were pulled up by forces of 250 or 500 lb by means of 1/4-in. (6.4-mm) steel cables which ran over pulleys to 250- (113-kg) or 500-lb (227-kg) weights. The long ends of the cables were attached to a hoist, which when raised pulled the spliced portions of the cable onto the bottom of the reel and when lowered, allowed them to move off and a foot (about 30 cm) beyond the reel. The pulleys supporting the weights were held up by a second hoist. The

cycling process was electrically controlled. Each cycle took 1 min with approximately 6 s required for moving the splice onto the reel, 24 s of rest, 6 s required to move the splice off the reel, and another 24 s of rest. The cables were attached with Kellems Grips, and the ends of these were secured with hose clamps to prevent slippage. The amount of travel during the flexing operation was controlled by limit switches.

Water Immersion Cycling

The spliced cables were placed into a steel tank 4-1/2 ft (137 cm) long, 2 ft (61 cm) wide, and 3-1/2 ft (107 cm) high lined with a 50-mil poly(vinylidine chloride) and epoxy liner, filled to a height of 3 ft (91 cm) with 3% saltwater. Each cable was held in a wooden yoke as shown in Figure 27. The cable was supported at the cable breakout boot at the short end of the cable and at a point 5 ft (152 cm) from the center of the splice on the long end of cable, so that the splice area was at the bottom of a U and almost touched the bottom of the tank. With this yoke the 100-lb (45.4-kg) cable could be individually handled, or four cables could be transported together with a forklift.

The saltwater was heated by steam passing through a 41-ft (12.5 m), 3/4-in. (1.9-cm) OD, 70-30 copper-nickel tube that went to the bottom of the tank, made nine traverses, and came up again, and then passing through a 26-ft (7.9-m) copper-nickel coil hung at one end of the tank. The bath was cooled by passing tapwater through the same tubing configuration. A valving arrangement allowed the return of the condensed steam to a condensate line and the discharge of the spent cooling water to the drain.

The upper and lower temperatures were maintained by a control unit with thermistor sensor that energized a solenoid valve. The saltwater was agitated by an external centrifugal pump which removed the saltwater 1 ft (about 30 cm) below the surface and returned it at the bottom of the tank through 3/4-in. (1.9-cm) chlorinated poly(vinyl chloride) piping. The thermistor temperature sensor was inserted in the flow path of this piping.

The steam was turned on at 0800 and allowed to flow through an open "coarse control" gate valve, which was closed when the 80C temperature was reached at about 0930, and the temperature was maintained within 0.5C by steam flowing through a "fine control" metering valve. The cold water was turned on at 1630 and allowed to flow through the "fine control" metering valve. Four turns of this valve produced a moderate flow of water, which was turned off by a timer and solenoid valve after 4 hr. Each morning the water that had evaporated in the previous cycle was replaced by adding demineralized water.

After the first and third complete cycles, insulation resistances were measured. The insulation resistance was also measured at the end of the hot portion of the fifth cycle. After the fifth cycle was completed by overnight cooling, the insulation resistance was measured, and the splices were subjected to the dielectric withstand test.

Electrical Measurements

The electrical measurements, to determine splice performance before and after the above exposures, were made with a Hipotronics highpot tester. This instrument supplied a variable high voltage (either AC or DC), which was displayed on a meter, and also measured the current flow. In the tank used for water immersion cycling, the copper-nickel tubing was used as a ground connection to the saltwater; and in a large plastic tank that was sometimes used for saltwater immersion, braided shielding was used to make the connection from the instrument ground to the saltwater. The following measurements were made:

Insulation Resistance. A potential of 1,000 VDC was applied to the conductors. The smallest division of the current meter represented 1 μA; no motion of the meter needle was interpreted as a current less than 0.1 μA, and indicated an insulation resistance of more than 10,000 MΩ. The maximum direct current reading was 5,000 μA, which would indicate an insulation resistance of 200 kΩ, and for lower resistance values the voltage was reduced. For some of the faulty cables, the voltages had to be reduced so far as to be illegible on the meter, and in these instances, a vacuum tube voltmeter was placed across the test leads. The resistance values obtained for the white insulated conductor and, therefore, for the test braid at the cable jacket inside the splice are shown in Table 1.

The insulation resistances of the black and the red insulated conductors were always so high (above 10,000 MΩ) as not to be measurable with this equipment. The only significant exceptions were in the insulation resistances of the hot cables at the end of the fifth heating period of the heat cycling. (These values were generally similar for the black and red conductors and were approximately as follows: Test splice SS-1, 10,000 MΩ; SS-2, 250 MΩ; SS-3, 60 MΩ; SS-4, 10,000 MΩ; SS-5, 10,000 MΩ; SS-6, 10,000 MΩ; SS-7, 10,000 MΩ; SS-8, 10,000 MΩ; SS-9, 250 MΩ; SS-10, 350 MΩ; SS-11, 100 MΩ; SS-12, 40 MΩ).

Dielectric Withstand Test. A potential of 2,200 VAC was applied to the conductor for 1 min. Splices in good condition gave current readings of approximately 1 mA (or slightly more) when immersed in saltwater. When the current flow increased above 5 mA, it was considered that the splice had failed the test. In such cases the voltage was reduced and the voltage that gave a 5-mA current flow was recorded. The results for the white insulated conductors are shown in Table 1. No failures were observed for the red or black conductors.

Abrasion

The abrasion resistance of the splices was determined by dragging the spliced cables and an unspliced cable on an asphaltic concrete roadway. The cables were attached to a horizontal bar mounted on a pickup truck as shown in Figure 28. The cables were pulled at approximately 5 mph (8 kmph) over an oval course 0.19 mile (0.30 km) long.

After one lap the cables were turned over and photographed (Figure 29), and the maximum width of each abrasion mark was measured. At this point, the shrinkable tubing splices were so damaged that they were removed. After a total of three, six, and ten laps, the cables were again turned over and photographed.

To calculate the approximate abrasion depth, the cross section of the splice was considered to be a perfect circle from which a segment had been worn off. The length of this segment, or the chord of the circle, was considered the width of the abraded area; and the depth of the segment was considered the abrasion depth. The latter was calculated using the formula

$$A = \frac{D - \sqrt{(D^2 - W^2)}}{2}$$

where A = abrasion depth

D = diameter of the splice or cable

W = width of the abraded area

The approximate abrasion depths after one lap and after ten laps are shown in Table 2.

DISCUSSION

The three-conductor, heat- and oil-resistant, flexible (THOF) cable used for shore-to-ship power is about 3 in. (7.6 cm) in diameter and carries 400 A of 480-V, three-phase, ungrounded current. A 150-ft (45-m) length of this insulated copper cable weighs 900 lb (408 kg), costs about $1,500, and is often difficult to obtain. If such a cable is damaged at the outer insulation only, it can often be patched, or shrinkable tubing can be placed over the damaged portion. If the damage extends to the insulation of the inner conductors, it may be worthwhile to cut the cable and splice it.

In the past, the THOF-400 cables were often used in lengths of 100 to 150 ft (30 to 45 m), and these were terminated by breaking out 2-ft (60-cm) lengths of the three individual conductors and attaching large lugs to each of these. These lugs were then attached to bus bars ashore or aboard ship. The lugs also were used to temporarily splice one length of cable to another length, and the three bolted connections typically were insulated with electrical tape, varnished cambric, and friction tape, and were separated from each other by a wooden block arrangement.

The use of lug connection is being discouraged. Ashore and aboard ship, bus bars are being replaced by MIL-C-24368 receptacles, and into these fit large plugs to which the power cables are attached [3]. The power cables can be potted into the plug assembly, but very often the plug assembly comes with a 6-ft (1.8-m) pigtail onto which the power

cable can be connected or spliced. When two sections of cable are connected for added length, the lugs may be replaced by three in-line connectors.* Alternatively, the cables may again be spliced to or terminated in the MIL-D-24368 plugs, and two plugs may be joined with a special phase-reversing double receptacle.

There has been little experience in the splicing of THOF-400 cable, except for some vulcanized splices that have been made. Possible splicing methods are discussed below. This is followed by discussions of possible test methods, of the preparation and performance of the splices, and of the significance of the results. The experimental work was limited to the THOF-400 cable, but the same principles would apply to the THOF-500 cable.

Splicing Materials and Methods

There is no generally accepted method for splicing the THOF-400 shore-to-ship cable. Various shipyards, other Naval facilities, and private concerns that have large molding presses have made vulcanized splices with this cable. Little work has been done using other methods that may either be less complicated or require little investment in equipment.

Large heat-shrinkable tubing is available and has been used for repairing or covering damaged areas of the THOF cable but apparently has not been used for splicing this cable. Such tubing, with an expanded diameter of about 4 in. (10 cm) and with an adhesive liner, is available from the three major manufacturers** of heat-shrinkable tubing. The heat-shrinkable tubing supplied for this purpose is made of cross-linked polyolefin. The cross linking is obtained by radiation or by chemical reaction, and the tubing is expanded while hot and then cooled. Subsequent heating of the expanded tubing will allow it to flow and to attempt to regain its original dimensions. For heating small shrinkable tubing, an electric heat gun is most suitable; but for shrinking large tubing, a propane hand torch that can provide an 18-in. (45-cm) flame is most suitable.

Large amounts of smaller flexible electrical cables are used in mining operations, and the three manufacturers cited supply kits for splicing such cables with heat-shrinkable tubing.*** These kits contain inner shrinkable sleeves to cover the connectors and outer shrinkable sleeves to cover the completed splice; they may contain filling materials, other splicing materials, and instructions. The Bureau of Mines is

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*Some of these have proved to be dangerous, and new ones are being developed.

**Electronized Chemicls Corporation (ECC), Raychem Corporation, and Sigmaform Corporation.

***ECC distributes these through Cable Associates, a subsidiary company.

interested in such splices and sponsored a study of various mine splices by Pennsylvania State University [4]. This study found that performance varies considerably and attributed most failures to workmanship defects. The Bureau of Mines has certified shrinkable tubing from the above manufacturers for use in mine splices. However, though the certification tests include tests for fire resistance, they do not include electrical qualifications.

The heat-shrinkable tubing mine splice kits are available for the smaller flexible cables used in mines but not for the THOF-400 cable. However, sufficiently large tubing is available and was obtained, together with other required materials. A splicing technique was then developed. For the insulation of the spliced inner conductor, shrinkable tubing similar to that used for the underground distribution cables was chosen [1].

It was desired to compare the heat-shrinkable tubing splices with vulcanized splices that could be made with portable molding presses. One such press is the Bench Type Cable Vulcanizer manufactured by Joy Manufacturing Company; another is the Hotsplicer Heavy Duty Molding Press made by Hexcel Corporation.

The Joy vulcanizer accommodates molds up to 30 in. (76 cm) long and is for pressure molding, in which the proper amount of unvulcanized material is applied to the cold splice and very little of this is lost during the vulcanizing.

The Hotsplicer method uses a transfer process in which a slight excess of unvulcanized material applied to the cold splice and additional warm unvulcanized material is forced into the closed, warm mold cavity just before the splice is vulcanized. The purpose of transferring the additional unvulcanized material is to fill any voids and to allow accumulated air to escape through bleed holes and at the cable jacket. This is important for the high voltage applications for which the Hotsplicer method was designed. The Hotsplicer press is intended for molds no longer than 24 in. (61 cm).

For the flexible neoprene-sheathed THOF cable, a neoprene vulcanizing material is recommended for the splice cover. Various unvulcanized or partially vulcanized tapes of neoprene or rubber are available for the insulation of the spliced conductors, and cloth-reinforced tapes are available to give added strength. It is also possible to insulate the inner conductors with heat-shrinkable tubing. In this manner a known thickness of insulation is provided that will not shift during the vulcanizing process, and this is the method that was chosen.

A variety of materials, including epoxies, silicones, and polyurethanes, are available for molding splices without the use of heat. Such ambient-temperature-cured materials are sometimes called "room-temperature vulcanized," which is a misnomer. No external heat is applied for these polymerization reactions, and although the temperature may rise because of the heat of reaction, it does not reach customary vulcanization temperatures. Most of the splices made in this manner are much too rigid for flexible cable. However, a flexible ambient-temperature-cured

polyurethane insulating material has recently been made available by the Products Research and Chemical Corporation. In cooperation with this company, a mold was developed for the use of this material for shore-to-ship cable splices. Heat-shrinkable tubing lined with adhesive was again used to insulate the spliced conductors.

Test Methods

There are no established methods of testing spliced shore-to-ship cable. For the testing of shrinkable splice covers for single-conductor underground distribution cables [1], a series of methods were selected from the methods of the National Electrical Manufacturer's Association (NEMA) [5] and of the Western Underground Committee [6] for 600-V underground splices and multitap junctions. These included overnight immersion, water-immersion heat cycling, flexing and twisting, and current cycling. Each test method was followed by overnight immersion in saltwater and measurement of the insulation resistance; a voltage withstand test was made at the end of the experiments.

For the spliced single-conductor cables it was a simple matter to detect failure of the splice by insulation resistance measurements. For the spliced three-conductor cables such measurements could be misleading. If each of the three spliced conductors are covered by heat-shrinkable tubing and the whole splice is covered by large shrinkable tubing, the failure of any of these four shrinkable tubings would not appreciably affect the insulation resistance between any two of the three conductors or between any of them and the surrounding saltwater.

It would be very difficult to detect any failure in the insulation of the spliced conductors, especially when the splice was filled with a nonconducting filler. It was, however, possible to detect any failure of the outside insulation along the cable jacket by attaching a wire screen electrode at the cutoff end of the cable jacket and connecting it to one of the conductors. This electrode was connected to the spliced white insulated conductor in the center of the splice (as shown in Figure 30), and the resistance between the white conductor and the saltwater bath was therefore the same as the insulation resistance along the two covered portions of the cable jackets, electrically in parallel.

A flexing test was considered very important for the flexible cable. It was believed that the best method would be to reel the cable under tension onto and off the core of a reel similar to one that might be used for cable storage. The method was described in the experimental section and was shown in Figure 26. Initially, 250 lb (113 kg) of tension was used and later 500 lb (227 kg). These appeared to be reasonable figures because the force required to drag a 150-ft (46-m) length of cable, weighing 900 lb (408 kg), along the deck of a ship was 600 lb (272 kg).

The water-immersion heat cycling used previously was used again because it provided a good test for the adhesive liner of the outer shrinkable tubing. The bath in which the saltwater was left at 80C for

7 hr each day and cooled to 25C overnight had to be greatly enlarged.

The current cycling used earlier was omitted. In this test method, the splice had been heated to 90C by applying a large current, and it was rapidly cooled by immersion in water. It would be difficult to rapidly cool the inner conductors of a large splice, and it would also be difficult to determine the temperatures of the spliced conductors.

An abrasion test was also considered important. Rather than subjecting each splice material to a Taber abrader or abrading the splice with a file or other abrasive material, the completed splices that had been subjected to the other test methods were dragged over an asphaltic concrete course. Such an exposure is more similar to what might happen in practice and is likely to give more valid comparative information than a laboratory test.

Preparation of Splices

Inner Splices. The copper conductors of the THOF-400 cable were butt-connected with copper compression sleeves. The 2052-strand conductors did not fit into 400 MCM sleeves, and 500 MCM sleeves were used. Although this sleeve left some play before compression (Burndy sleeves were more snug than other sleeves that were tried), it could be compressed with a manual hydraulic press to produce a tight connection with an ultimate tensile strength of 7,400 lb (3,350 kg).

The splice was kept as short as practical to allow use of shorter splice covers. The 18-in. (45-cm) space between the cut cable jackets was the minimum needed when the three 3-in. (7.6-cm) compression sleeves were centered in the splice and staggered 1 in. (2.5 cm) apart and when the conductors were kept in the proper lay and assembled with 7-in. (17.8-cm) heat-shrinkable tubing for the insulation of the compression sleeves. A further shortening of the splice would have made it difficult to manipulate the cable and the manual hydraulic press during splicing. (By staggering the compression sleeves only 1/2-in. (1.3-cm) apart and using 6-in. (15-cm) heat-shrinkable tubing, a 16-in. (40-cm) splice was prepared for the Hotsplicer vulcanized splice.)

The preparation of the inner portion of the splice, as described in the experimental section and in more detail in the Appendix, required 3.5 hr for an experienced technician working alone.

Shrinkable Splice Covers. The longest heat-shrinkable outer sleeve available from Raychem was a nominal 30 in. (76 cm) long and was a little over 27 in. (69 cm) long after application. This sleeve, therefore, covered each cable jacket 4.5 in. (11.5 cm) out from the 18-in. (45-cm) inner splice — or a distance of 1-1/2 cable diameters. The ECC Dura-Splice and the Sigmaform mine-type sleeves were available and were used in 36-in. (92 cm) lengths. The applied lengths were 35 and 34 in. (89 and 86 cm), and therefore the coverages of the cable jackets were about 8.5 and 8 in. (22 and 20 cm), respectively.

Opinion of manufacturer representatives differed on whether a filler was needed between the insulated conductors and the outer sleeve,

essentially to replace the jute filler of the original cable and to make a smooth round splice. A sample splice without filler was prepared, but this had very sharp edges at the ends of the inner splice which appeared to be very stressed during flexing and which would probably be exposed to excessive abrasion. Another sample splice was filled by winding with marlin cord, but this required considerable time and produced a comparatively stiff splice. Either AMP dielectric and sealing compound or Raychem dielectric filler were suitable as fillers. These are available in 1/8-in.-thick ribbons 3-3/4 and 2 in. wide, respectively. The former would have been easier to use if it had been less sticky and less pliable; the latter would have been easier to use if it had been more sticky and more pliable because it would have stayed in place better. Both fillers were sufficiently sticky that it was difficult to slip the outer sleeve (with its adhesive liner) over the filled inner splice. The filled portion was therefore covered with varnished cambric before the outer sleeve was slipped over it and was shrunk on.

The shrinking on of the outer sleeve with a large propane flame required about 15 min. The filling of the splice and the application of the outer sleeve, as described in the experimental section and in more detail in the Appendix, required about 1.3 hr, for an experienced technican working alone (except for help in slipping the expanded sleeve over the splice). After completion, the splice was allowed to cool for at least 2 hours before it was moved.

Vulcanized Splice Covers. Two types of vulcanized splice covers were used in the experiments. One of these was made with a Joy vulcanizer aboard the *U.S.S. Dixon*, by a procedure that the crew had extensively used for repair of the THOF-400 cable. This procedure included a mold made aboard ship, and a tread repair gum rather than the more expensive recommended neoprene vulcanizing material was used. The inner splice with metal screen electrodes had been made at CEL.

A second type of vulcanized splice was made by the Hotsplicer method. For this large flexible cable, the manufacturer had recommended a 36-in. (92-cm) mold, which would have required two molding presses, but by reducing the inner splice length from 18 in. (46 cm) to 16 in. (40 cm), it was possible to use a 24-in. (61-cm) mold with one molding press. The manufacturer had suggested a 3.75-in. (9.5-cm) mold cavity, but by keeping the cable under tension during the vulcanizing to keep it in the center of the mold, it was possible to use a 3.25-in. (8.3-cm) mold cavity and thereby increase the flexibility of the splice.

In the Hotsplicer method, the spliced conductors would normally be covered with a partially vulcanized rubber insulating tape before the unvulcanized neoprene tape is applied and the splice vulcanized. The partially vulcanized tape will not flow during the vulcanizing and will insure a minimum insulation of the compression sleeve. This objective was met even better and with less effort by the use of shrinkable tubing. The Raychem tubing was chosen because its hot-melt adhesive liner had a higher softening temperature than that of the other inner shrinkable sleeves. The Raychem tubing also had the greatest applied thickness, which was 0.122 in. (3.1 mm) without adhesive or about 0.15 in. (3.8 mm) with the adhesive layer.

The extruded adhesive from the inner sleeve was covered with "transitape" (a gray, natural rubber tape) to prevent mixing with the unvulcanized neoprene. Between the inner conductors, some of the green unvulcanized neoprene was placed, and the resulting bundle was covered with black nylon-reinforced binding tape for added strength. More of the green neoprene was wound on the splice and heated beyond its flow point of 225F (107C). Additional warm neoprene was added through the transfer pot, and the splice was vulcanized at 325F (163C).

In the preparation of sample splices it became obvious that several precautions need to be taken. If insufficient neoprene is placed into the press under the splice, the conductors could sag and leave reduced insulation at that area. To minimize this possibility, the splice was kept under tension during the vulcanizing process. Proper cleaning of the cable jacket is also very important for proper adhesion, even if the correct bonding agent is used. The cable jacket should be abraded sufficiently so that no shiny or smooth area remains. The unvulcanized neoprene has a shelf life of 6 mo if it is refrigerated right after delivery. If it has passed its shelf life, it cannot be properly transferred and will have poor adhesion.

A cross section of the completed splice is shown in Figure 31. An advantage of the green neoprene splice cover is that any abrasion to the black reinforcing tape, black shrinkable sleeves, or black cable jacket can be seen readily.

The time required to make the Hotsplicer splice cover for the prepared basic splice was about 2.5 hr, plus the vulcanizing and cooling times. During part of this time, a second person helped and thus about 4.0 man-hr were required.

Ambient-Temperature-Cured Splice Covers. The ambient-temperature-cured polyurethane insulating material that was used for the last type of splice had previously been used for molding or encapsulating small connections, and a method for making the large splices was developed with the manufacturer. A horizontal mold with liner did not work well, and the resultant splice was very stiff. PRC made the vertical mold, shown in Figures 23 and 24, in which the cable could be held straight by attaching a weight; and it reformulated the PR 498-1/4 material to provide a more flexible product. According to PRC, cleaning of the cable jacket prior to applying the splice cover is more important for the polyurethane splice than for the other splices. Removal of all shiny surfaces of the cable jacket with a high-speed rotary file was recommended.

The PR 498-1/4 material was supplied in a two-component system in 20-oz (590 ml) Semkit containers. In the Semkits the two premeasured components, originally separated by a barrier, are mixed by agitation with a plunger. Mixing of the five 20-oz (590-ml) Semkits appeared to present no problem, but the material actually was not mixed well enough and when the completed splice was cut into sections, pockets of unreacted isocyanate material were found. When the same splice was made with thirteen 8-oz (235-ml) two-component Semkits, good mixing and a good splice cover resulted.

The mixing of 13 kits took considerable effort, and good mixing could not be achieved with the 20-oz (590-ml) kits. Two splices were therefore made with the PR 498-1/4 material supplied as a three-component system in cans. The two main components were mixed with a spatula, and after the addition of catalyst the material was mixed again. Three sets of 27-oz (800-ml) kits of the PR 498-1/4 would be required for one splice. The first time the material was mixed, the mixing was not complete and pockets of unreacted material resulted. The second time the material was mixed no unreacted material remained, but considerable entrained air was found.

For the splices used in the test sequence, the PR 498-1/4 was supplied in 1/10-gal (380-ml), three-component Semkits. Eight such Semkits were required for each splice. Each kit was mixed for a few minutes to blend the major components; the catalyst was injected from the plunger handle; the kit was then vigorously mixed about 30 s; and the mixture was injected into the mold. The new Semkits did not appear as well made as the older ones, and sometimes the plunger was difficult to move or became stuck. The effort required to mix the 8 three-component Semkits was much more than for the 13 two-component Semkits used earlier.

A cross section of the completed splice is shown in Figure 32. The section on the right was cut with a bandsaw, and the fine protrusions are unreacted material. The section on the left was polished with a belt sander, which opened a passage that allowed some unreacted material to ooze out into a bead.

The time required for two persons to make the polyurethane splice cover for the prepared basic splice was about 1.8 hr (or about 3.5 man-hr) plus overnight curing and removal from the mold. The mold release time was designed to be 2 hr, but the mixture was still too tacky to remove the mold after 4 hr.

Performance of Splices

If the criteria for good performance of the splices are only that continuity be maintained and that the conductors remain well-insulated from each other and from saltwater outside of the splice, then all the splices performed well after a total of 700 flexing cycles on a cable reel and a total of 10 heating cycles in a saltwater bath. If it is also required that the electrical integrity of the cable jacket be completely restored and that the splice be as abrasion resistant as the cable, then all the splices failed. Between these extremes, the experimental results indicate that all the splices could give adequate service but that potential problems exist.

The insulation resistances measured after each test exposure, and listed in Table 1, were for the electrical paths along the cable jackets from the saltwater to the wire screen electrodes. The average lengths of these paths varied from 3 in. (7.6 cm) for the Dixon splice to 8.5 in. (21.6 cm) for the ECC splice. After initial immersion in saltwater, these insulation resistances were above 5 MΩ for all the splices, except for the Dixon splices, which had negligible resistances.

The shrinkable tubing splices were moderately affected by the initial 300 flexing cycles whereas the others were not affected. The immersion heat cycling was expected to affect primarily the shrinkable tubing splices but to varying degrees it also affected some of the other splices. The low insulation-resistance values after heat cycling of the shrinkable tubing splices were sometimes dramatically increased by flexing, which probably redistributed the adhesive liner. The lowest insulation-resistance value reached by the shrinkable tubing splices was about 100kΩ.

The Dixon vulcanized splices had very low insulation-resistance values after the initial immersion. One of the PRC polyurethane splices failed during the heat cycling. The other PRC splice and the Hotsplicer vulcanized splice had high insulation resistance values after the final flexing cycles.

There is no recognized lower limit for the insulation resistance along the cable jackets, and this is not a measurement that is generally made. However, a very low value might indicate a possible leak of water into the splice and into the jute filler of the cable. (Moisture in the filler may produce a rupture when the cable is heated by placing it in service). Otherwise, a value of 100kΩ or lower might be acceptable as long as the inner conductors are well-insulated.

There is no indication of any failure of the inner heat-shrinkable sleeves at the spliced conductors, and none would be expected on the basis of previous experiments [1]. Additional insulation is provided between the inner sleeves and the cable jacket by the dielectric filler or the molded insulating material. Thus, a splice like the Dixon splice could provide greater electrical safety than three in-line connectors which have no outer jacket. However, a better seal at the cable jacket would provide greater confidence.

Two of the shrinkable tubing splices (Sigmaform and ECC) lost considerable adhesive from the ends of the splices during the heat cycling, as shown in Figure 33. For mine splices, the manufacturers often suggest covering the ends of the splice with additional shrinkable tubing without sealant. For the shore-to-ship cables they thought these end sleeves would not be necessary. However, a cleaner and probably better splice would have resulted. The end sleeves, made of thinner tubing than the splice covers, would have been about 6 in. long and centered over the ends of the splice covers, thus holding in the adhesive and the splice covers. The Raychem splice covers remained tight, and there was no loss of adhesion.

The vulcanized splices (Figures 33 a and b) and the ambient-temperature-cured splice (Figure 34) did not show any visual effect from the flexing or heat cycling, with the exception of the open crack in one of the polyurethane splices. This crack was not very large after the final flexing (as shown in Figure 34), but after the splice remained in a flexed position for 3 months, the crack extended half way around the splice and became 1/2 in. wide. The other ambient-temperature-cured splice did not show any defects during the testing, but after it remained on a reel for 7 months, it also had a large crack that extended almost half way around the splice.

The shrinkable tubing splices were more readily abraded than might have been expected in view of the toughness of the crosslinked polyolefin tubing. A contributing factor was the wrinkled shape that the shrinkable tubing assumed when the tubing was kept bent for a prolonged period. The resulting ridges, which are illustrated in Figure 33b, bear the weight of the dragged cable and are abraded first. The abrasion depths listed in Table 2 were calculated from the width of the abraded area and on the assumption that the cross section of the splice was a perfect circle. For the wrinkled shrinkable tubing splice covers, which were worn through at the ridges, these values are very approximate. The abrasion test represented extreme conditions, and the splices became very warm as they were dragged over the asphaltic concrete roadway. Occasional dragging for short distances should have much lesser effect on the splices.

The vulcanized and ambient-temperature-cured splices were abraded much less than the shrinkable tubing splices. These splices were not deformed by prolonged bending, and the abrasion wear was very even. If properly made, these splices have thicker covers than the shrinkable tubing splices and can be worn deeper without providing electrical dangers. But if molded splices are not properly made, portions of the insulated conductors could sometimes lie very near the surface and could be covered by very thin layers of splice cover. An advantage of the shrinkable tubing splice covers is that the insulated conductors are covered by outer insulation that has at least the wall thickness of the tubing.

The shrinkable tubing splice covers were sufficiently flexible to provide no problem in handling of the cable. The vulcanized splice covers were much more flexible. The polyurethane splice was the most flexible and could be bent almost as easily as the original cable.

The approximate costs of the various splices range from about $29 to $78 and from about 5 man-hr to 7-1/2 man-hr. These costs are further broken down for each splice in Table 3. The basic splice costs include $8 for the connectors and the inner sleeves. The splice cover costs include about $6 for dielectric filler and incidental materials, which are in addition to the costs of the outer sleeves, the vulcanizing materials, or the Semkits. The dollar costs are estimates per splice when materials for 20 splices are purchased. The Hotsplicer splice requires a press and mold costing $1,800. The Dixon splice, which is not listed in Table 3 because definitive information is not available, requires slightly less expensive equipment and materials than the Hotsplicer splice.

The manpower estimates in Table 3 are for one experienced technician working full time with some assistance in the vulcanizing or molding procedures. With experience, these manpower requirements might be reduced. The shrinkable tubing splice covers require less skill than the others. However, the splicing of shore-to-ship cables should not be entrusted to unskilled personnel.

CONCLUSIONS

1. Heat-shrinkable polyolefin tubing, lined with adhesive, provides good insulation for the spliced conductors of THOF-400 shore-to-ship cable, when used with various splice covers.

2. Heat-shrinkable polyolefin tubing can be used to make satisfactory splice covers for THOF-400 shore-to-ship cable, without much specialized equipment and with moderate skill. However, the insulation resistance and the abrasion resistance are not as good as for the original cable.

3. Vulcanized neoprene splice covers, properly prepared, provide excellent splice covers for shore-to-ship cable, but they require special equipment and slightly higher skill.

4. An ambient-temperature-cured polyurethane insulating material (PRC 498-1/4) has not been sufficiently well-developed for practical use as a splice cover for shore-to-ship cable. The application method requires high skill and is potentially hazardous, and after several months, both splices had developed deep cracks.

5. If the ambient-temperature-cured polyurethane insulating material and its method of application are further developed, this material would probably provide better splice covers than the shrinkable tubing, with a moderate additional effort and cost and without much specialized equipment.

6. The preparation of good shore-to-ship cable splices requires moderate skill and considerable care. The time required is from 5 to 8 man-hr, and the material costs range from $30 to $80.

ACKNOWLEDGMENT

The assistance of Mr. Joseph Quigley in the preparation and testing of the splices, and his helpful suggestions are gratefully appreciated.

REFERENCES

1. Naval Civil Engineering Laboratory. *Technical Note N-1325: Shrinkable Splice Covers for Underground Distribution Cables*, by Peter J. Hearst. Port Hueneme, Calif., Dec 1973.

2. Military Specification, MIL-C-915/6E: Cable, electrical, 600 volts, types, SHOF, DHOF, THOF, and FHOF, 4 Sep 1973.

3. Military Specification, MIL-C-24368A: Connector assemblies, plugs and receptacles, electric, power transfer, shore to ship..., 1 Mar 1972.

4. Pennsylvania State University. USBM Grant No. GO-133077 Final Report: Mine electrical systems evaluation — cable splicing, by Robert Stefanko, Lloyd A. Morbey, and Robert King. University Park, Pa., Jul 1974.

5. National Electrical Manufacturer's Association. Publication No. CC-P1-1969: Official standards proposal, sealed insulated underground connector systems rated 600 volts. New York, N.Y., Nov 1969.

6. Western Underground Committee. Guide No. 2.4: Heat-shrinkable splice tubing, revised 2 Feb 1968. (This guide is also included in an appendix in Reference 1).

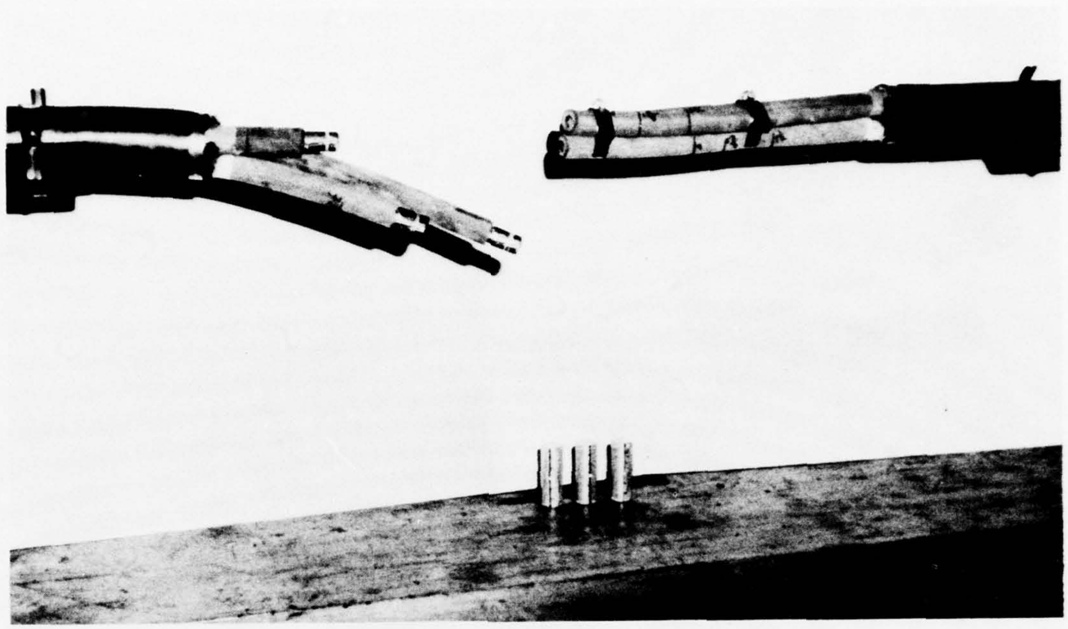


Figure 1. Splicing of conductors of THOF-400 cable, showing the cut-off cables.

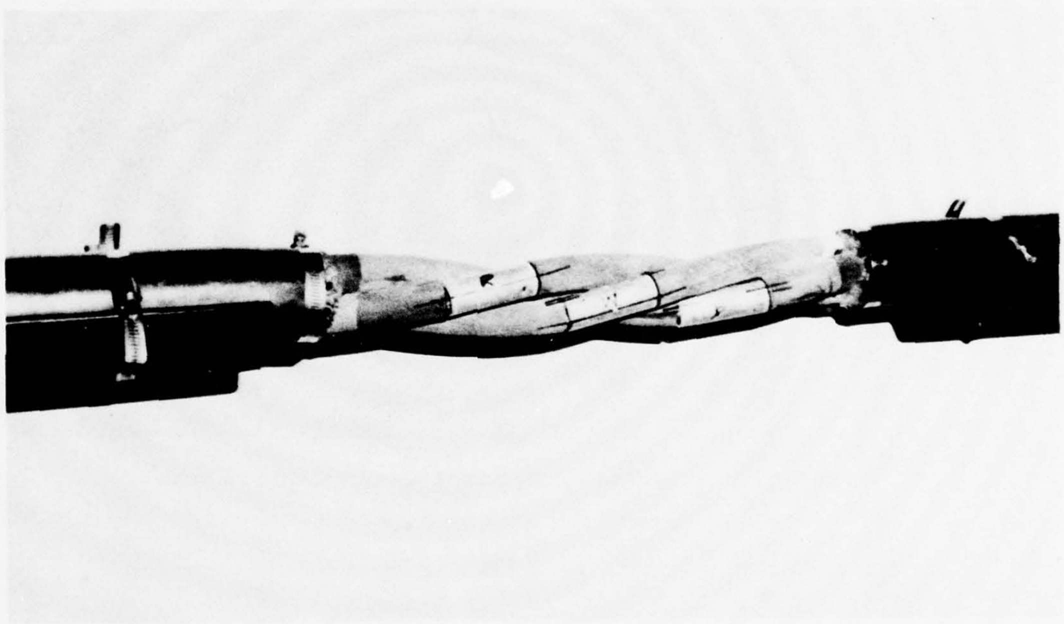


Figure 2. Conductors and compression sleeve marked for proper contact.

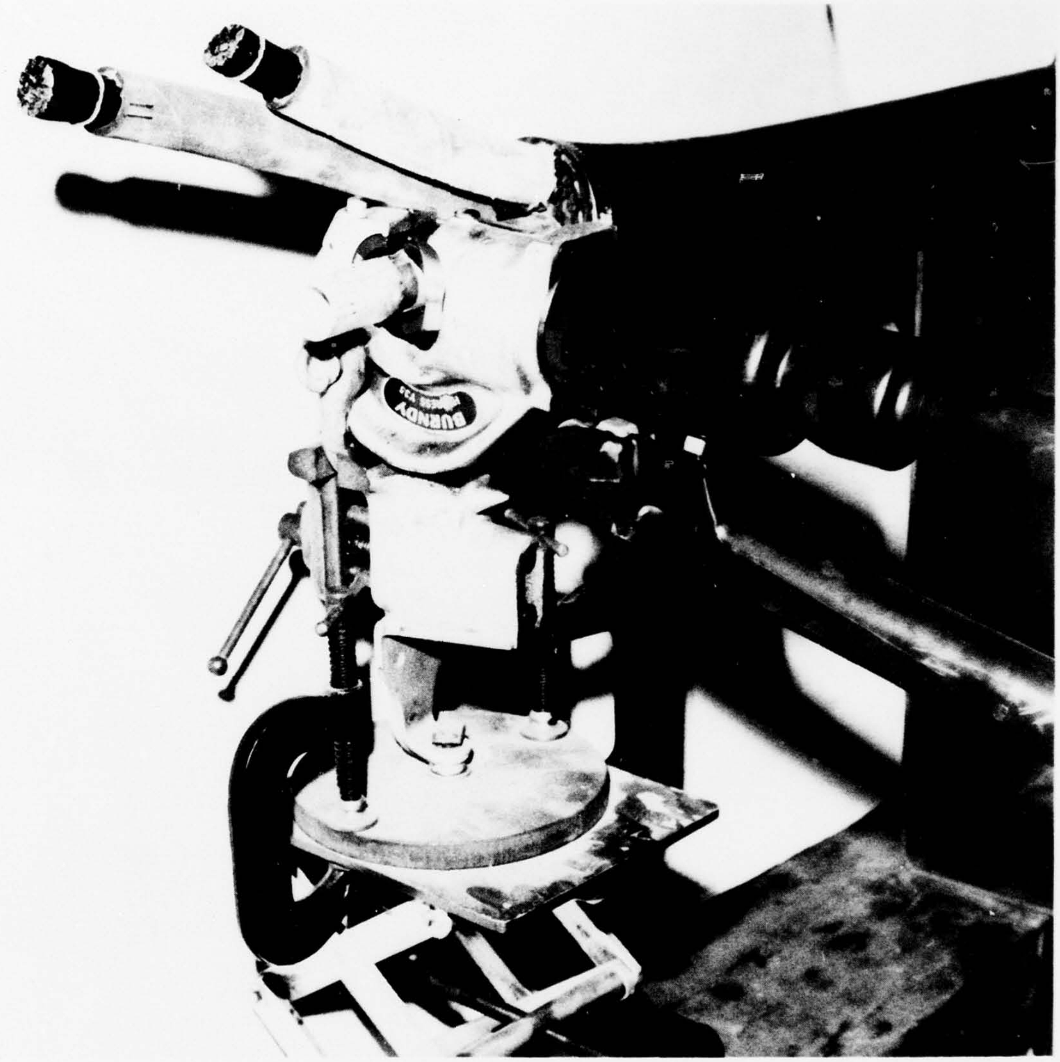


Figure 3. Attachment of first compression sleeve.

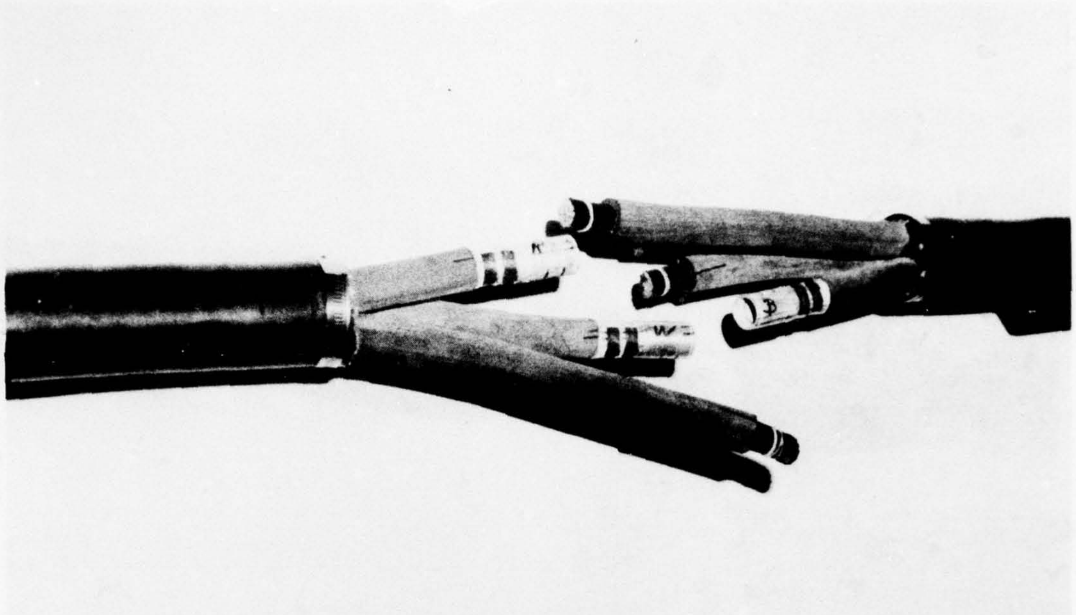


Figure 4. Cables with one side of each compression sleeve attached.

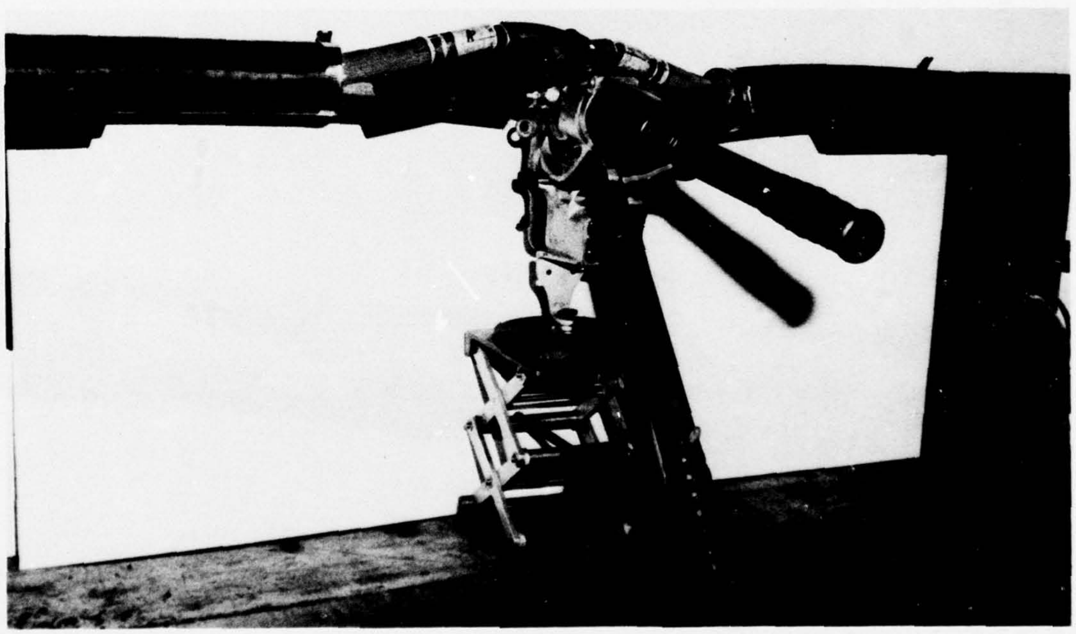


Figure 5. Splicing of conductors.

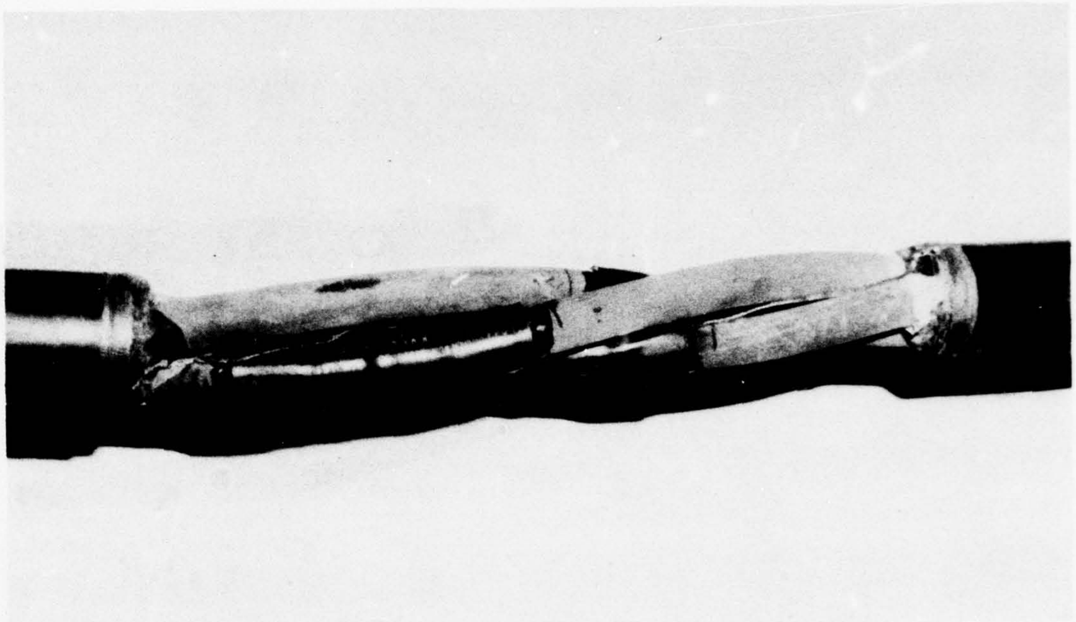


Figure 6. Spliced conductors with test braid and shrinkable sleeves installed.

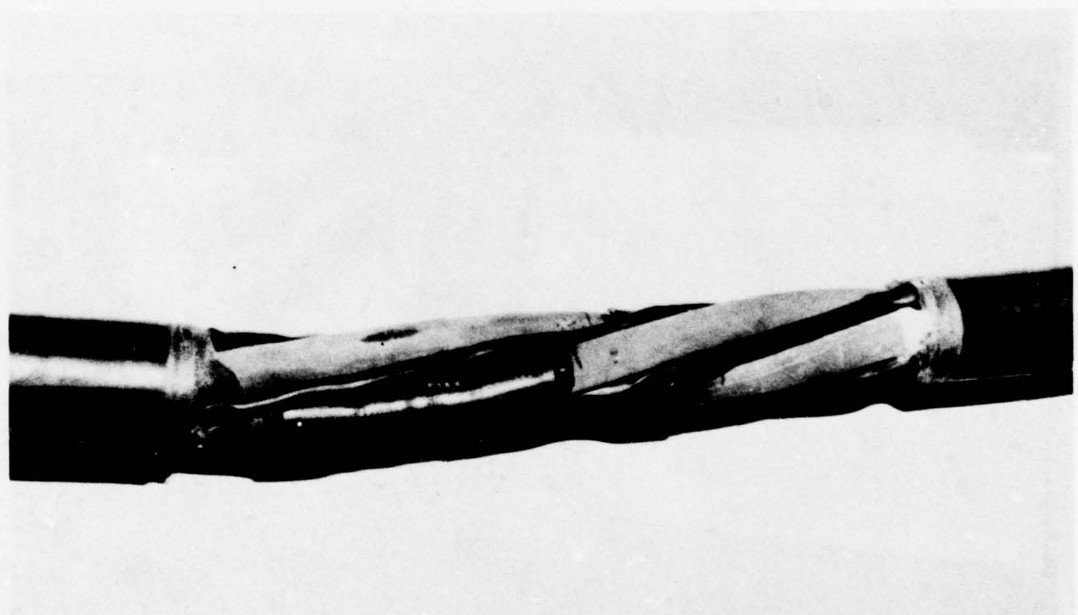


Figure 7. Preparation of shrinkable tubing splice cover, with one set of dielectric strips installed.

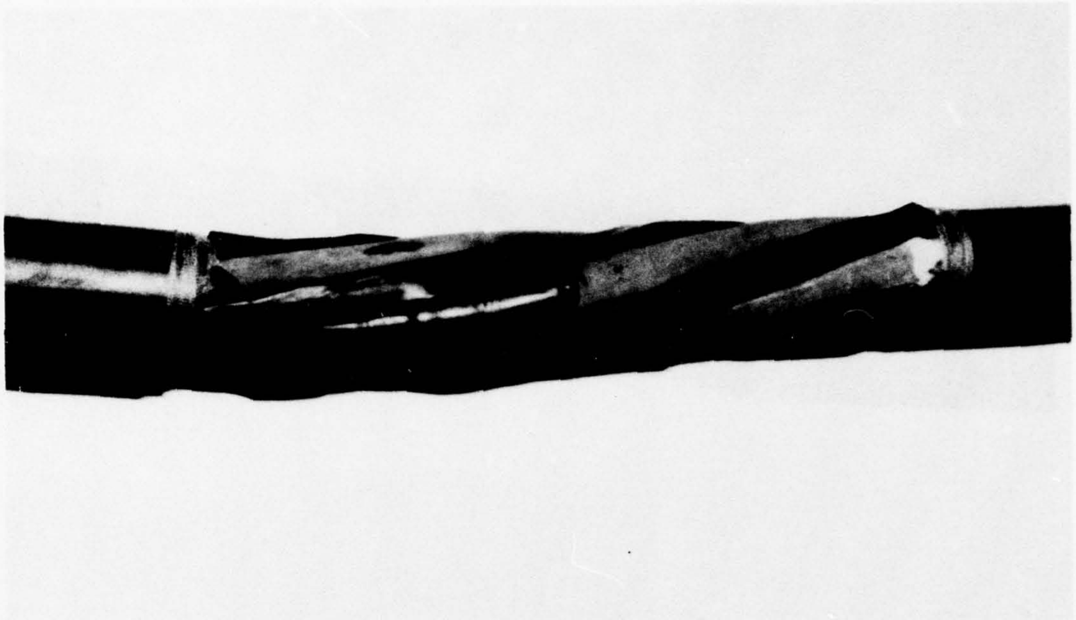


Figure 8. Two sets of dielectric strips installed.

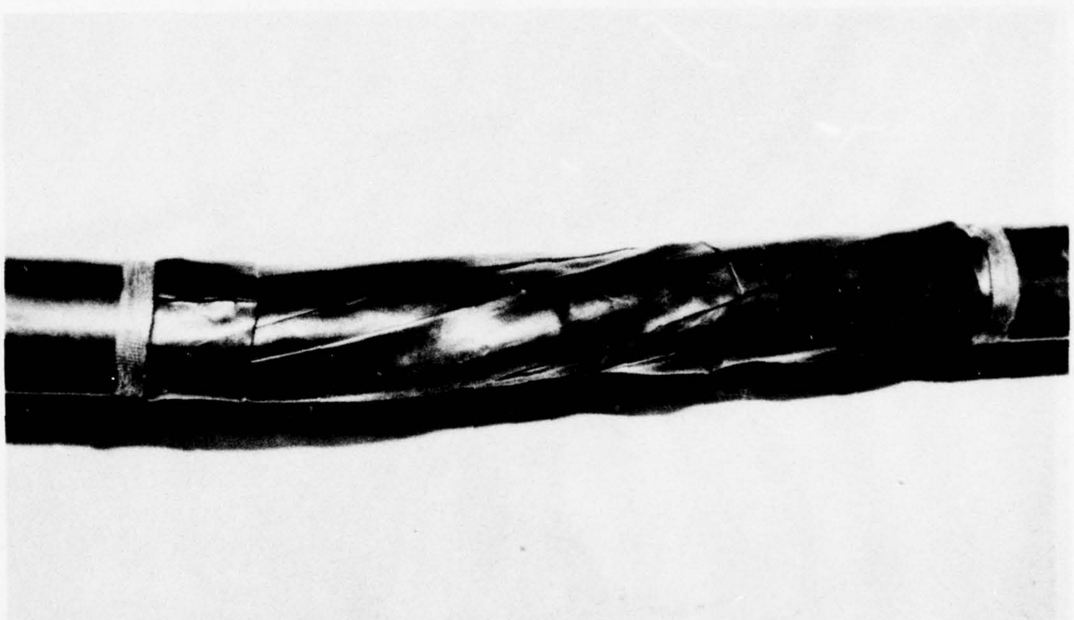


Figure 9. Dielectric filler installed.

Figure 10. Dielectric filler covered with varnished cambric.

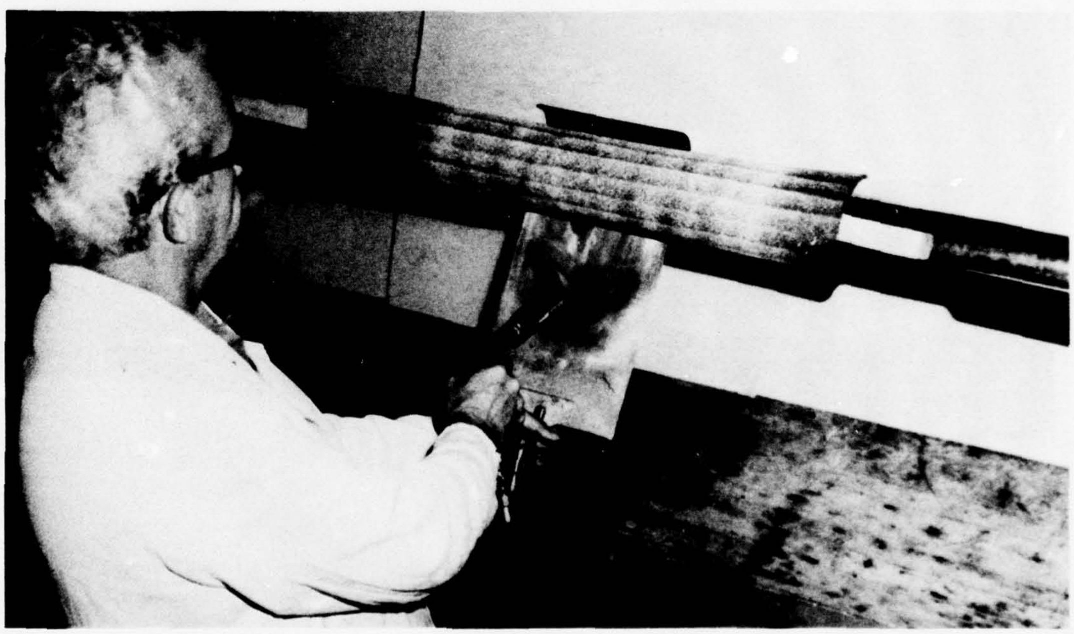


Figure 11. Heating of shrinkable sleeve.

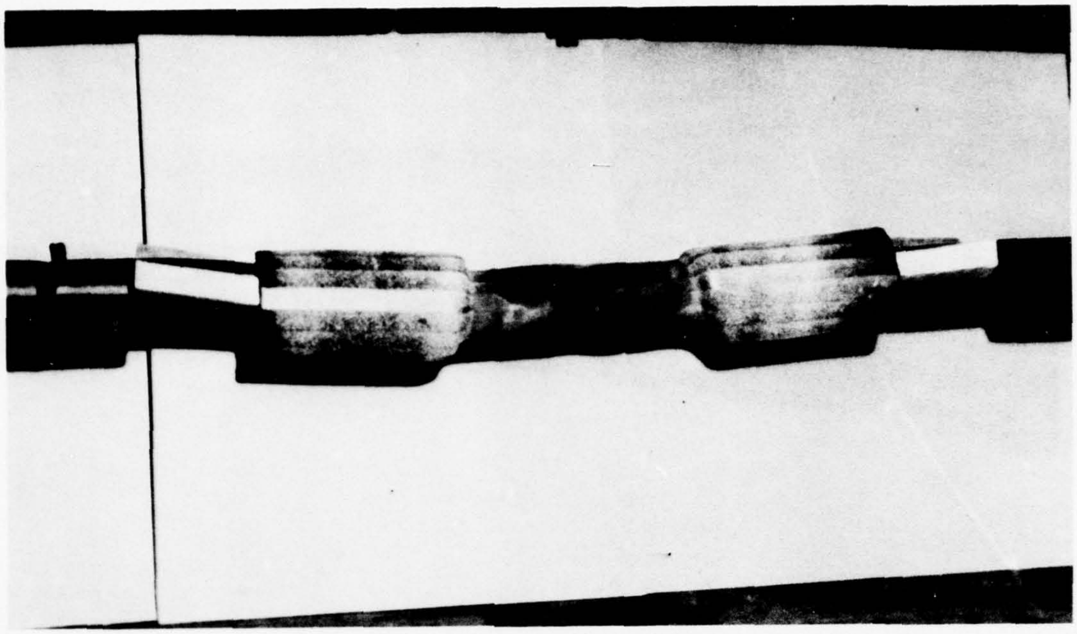


Figure 12. Partly shrunk sleeve.

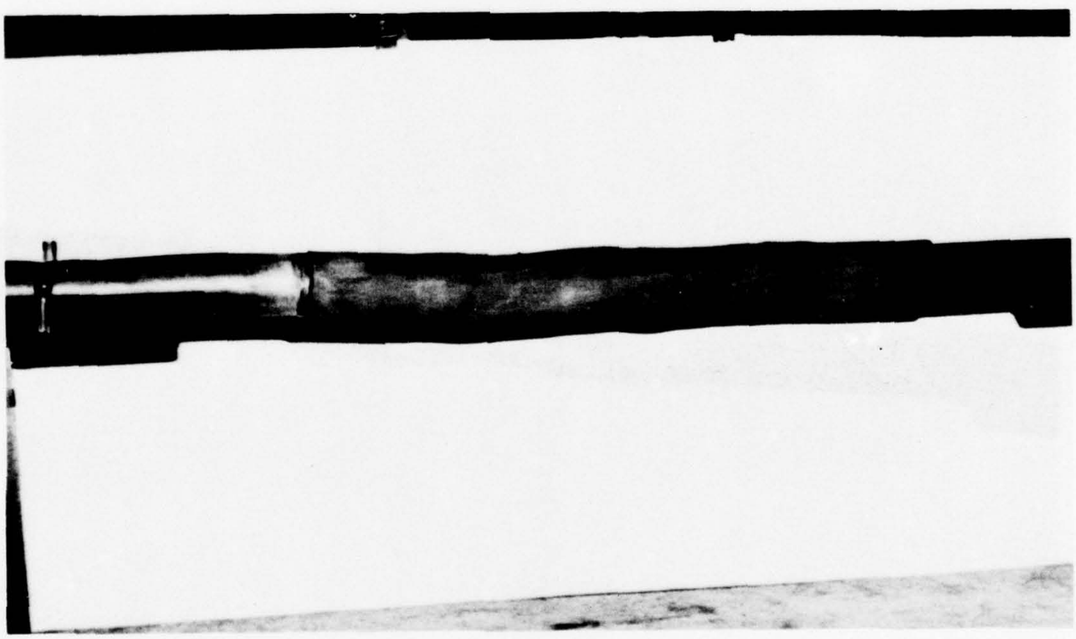


Figure 13. Finished shrinkable tubing splice.

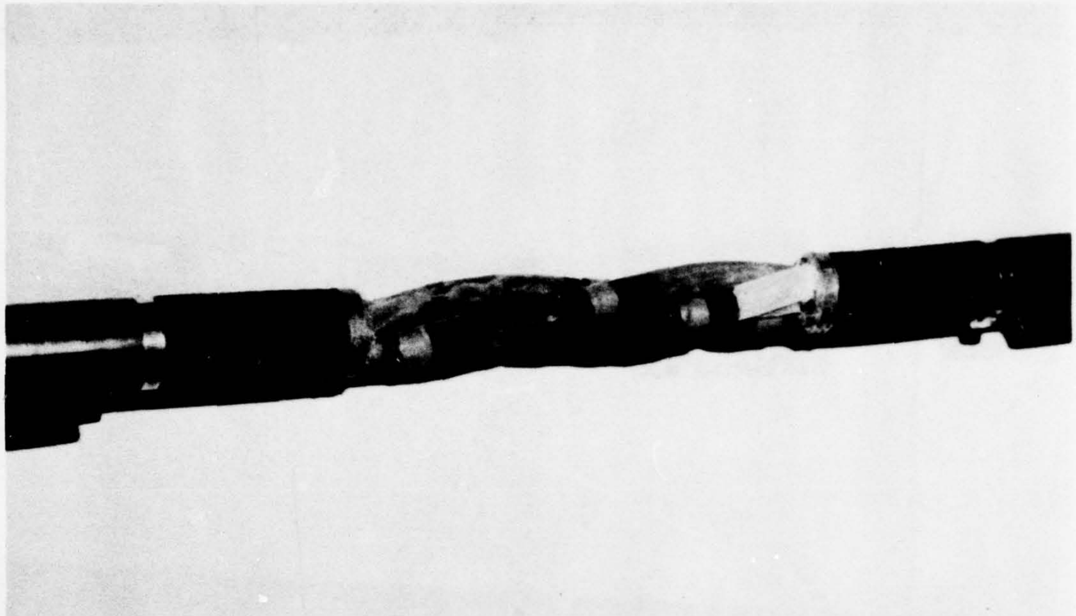


Figure 14. Preparation of vulcanized splice cover, showing adhesive covered with transitape.

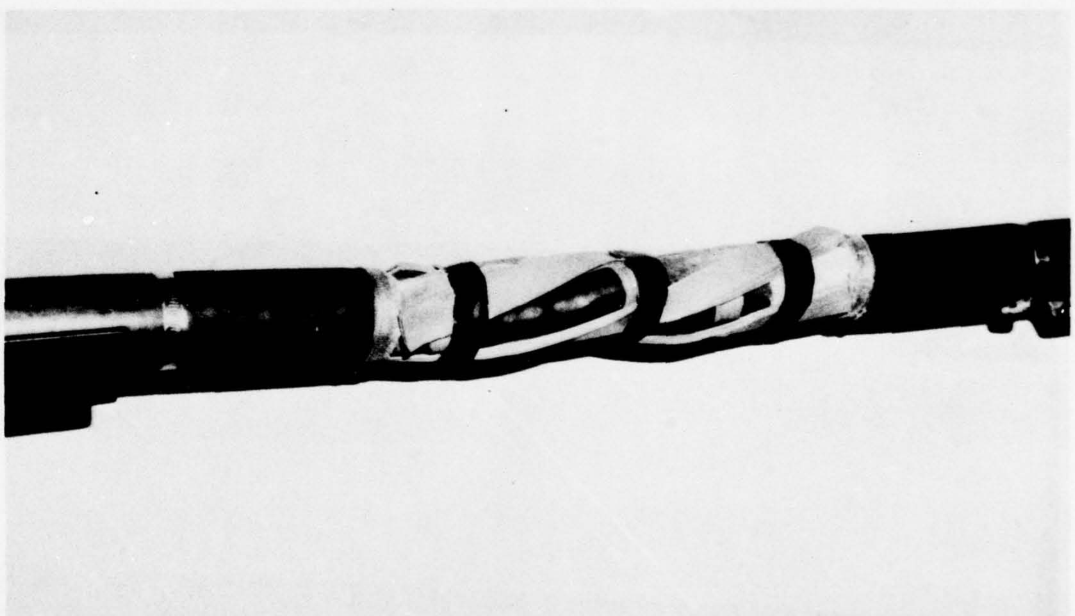


Figure 15. Inner neoprene layer held with binding tape.

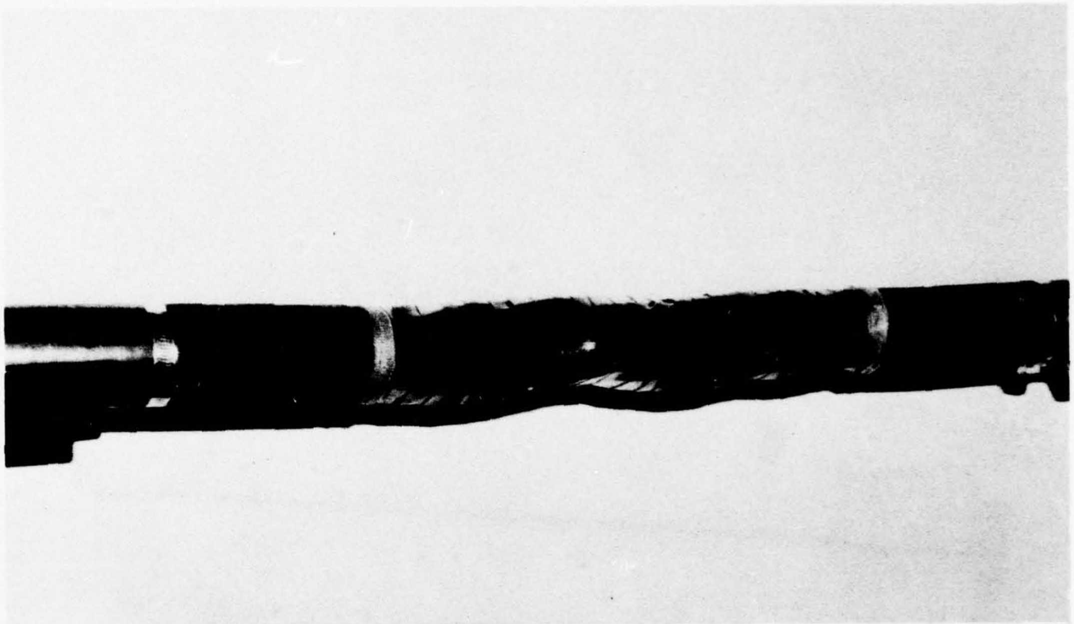


Figure 16. Layer of binding tape completed.

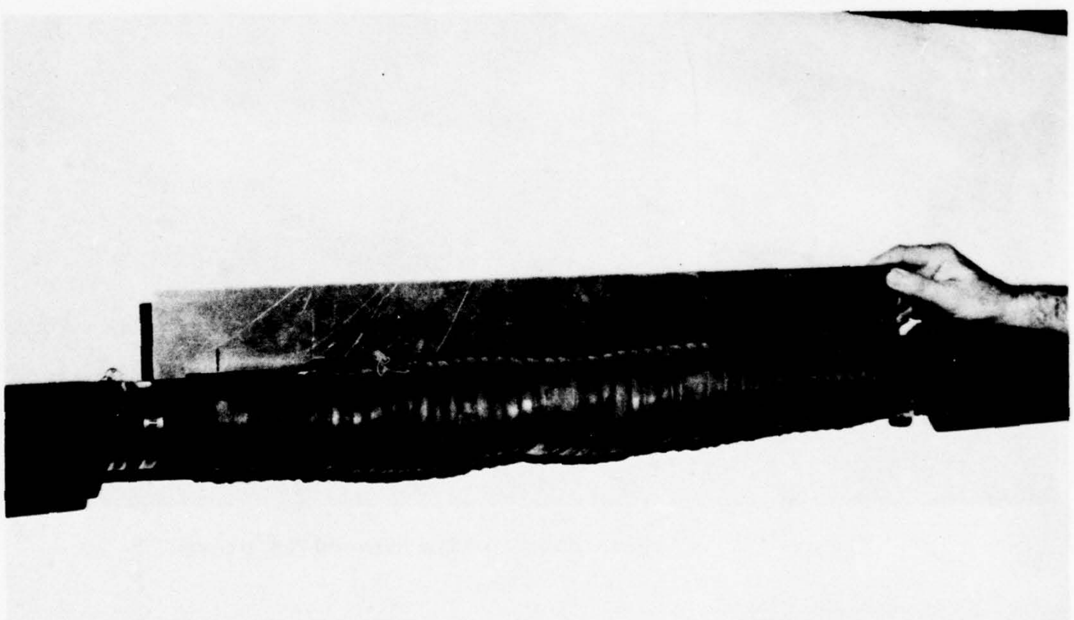


Figure 17. Layer of unvulcanized neoprene added.

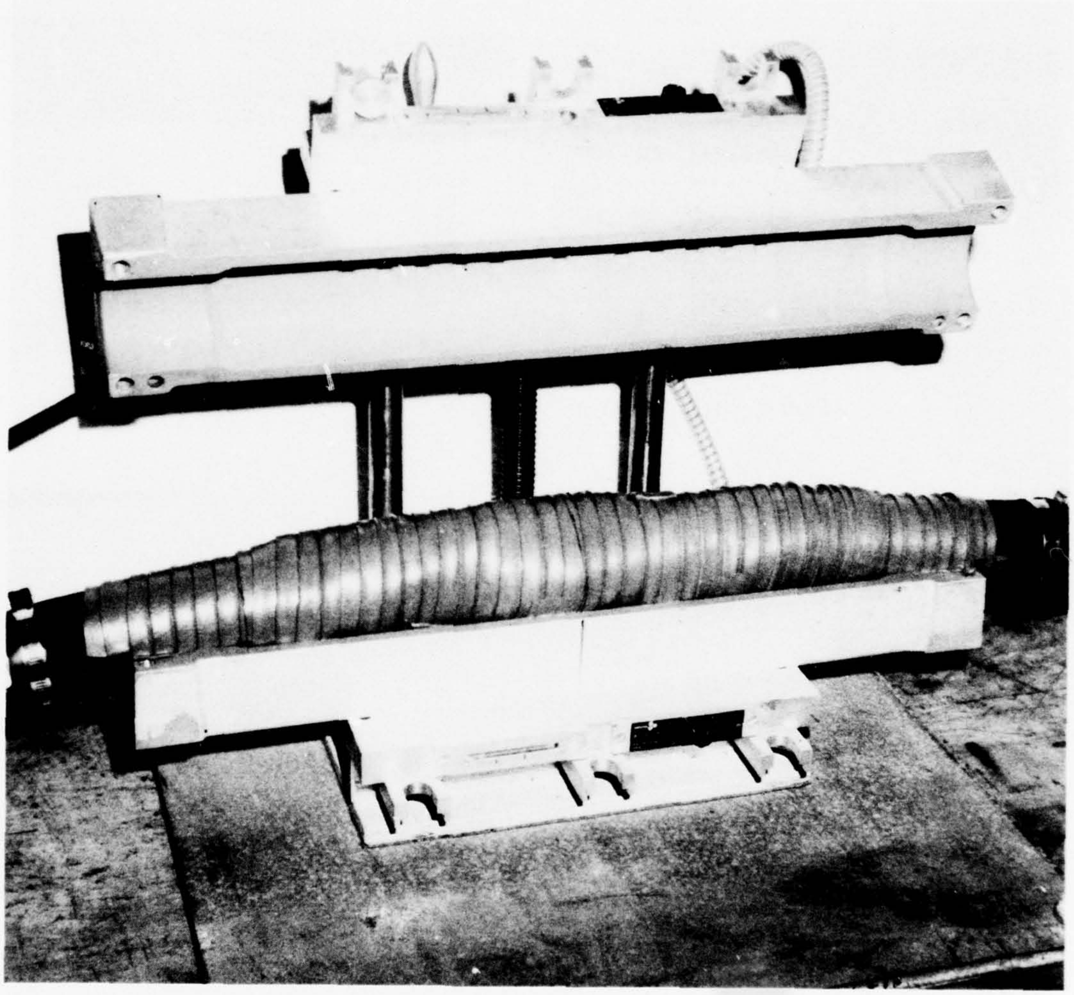


Figure 18. Unvulcanized splice placed in press.

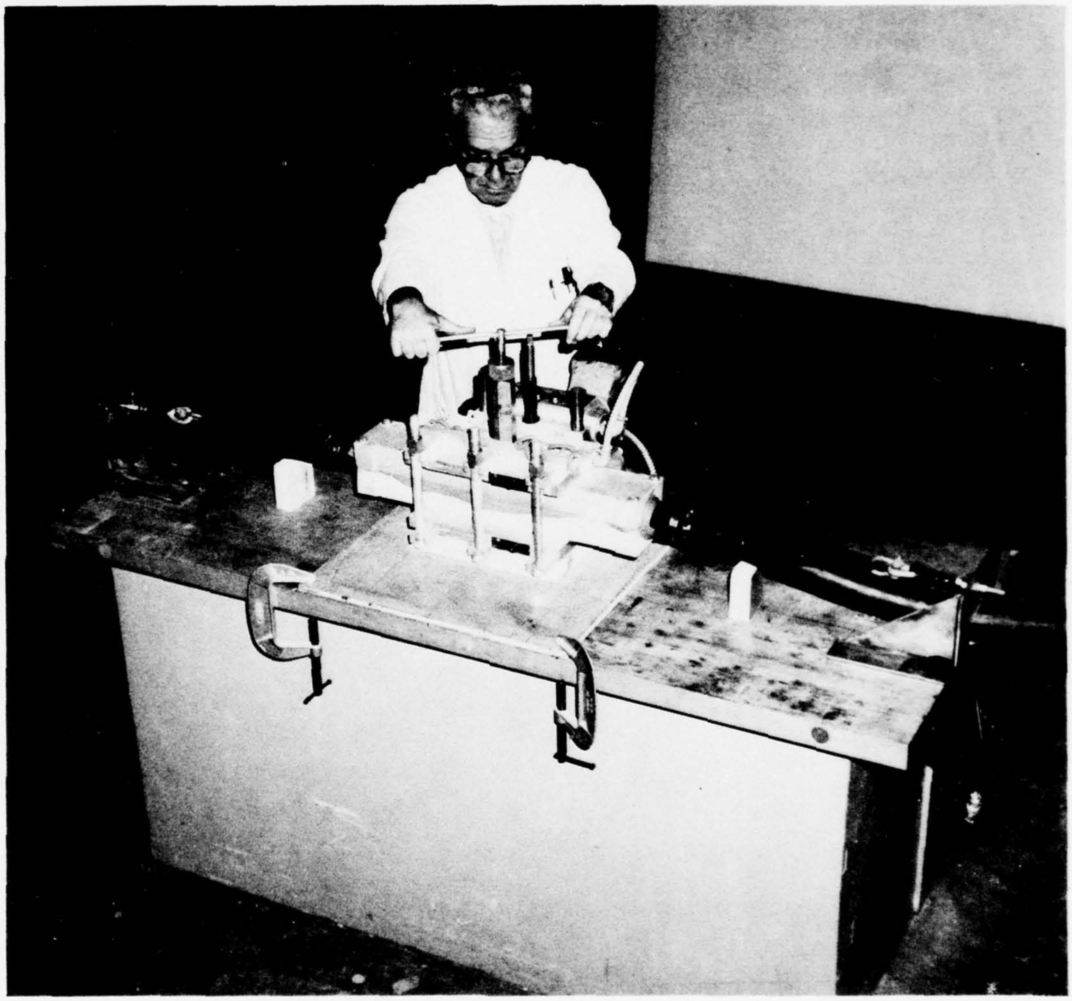


Figure 19. Injection of neoprene from transfer pot.

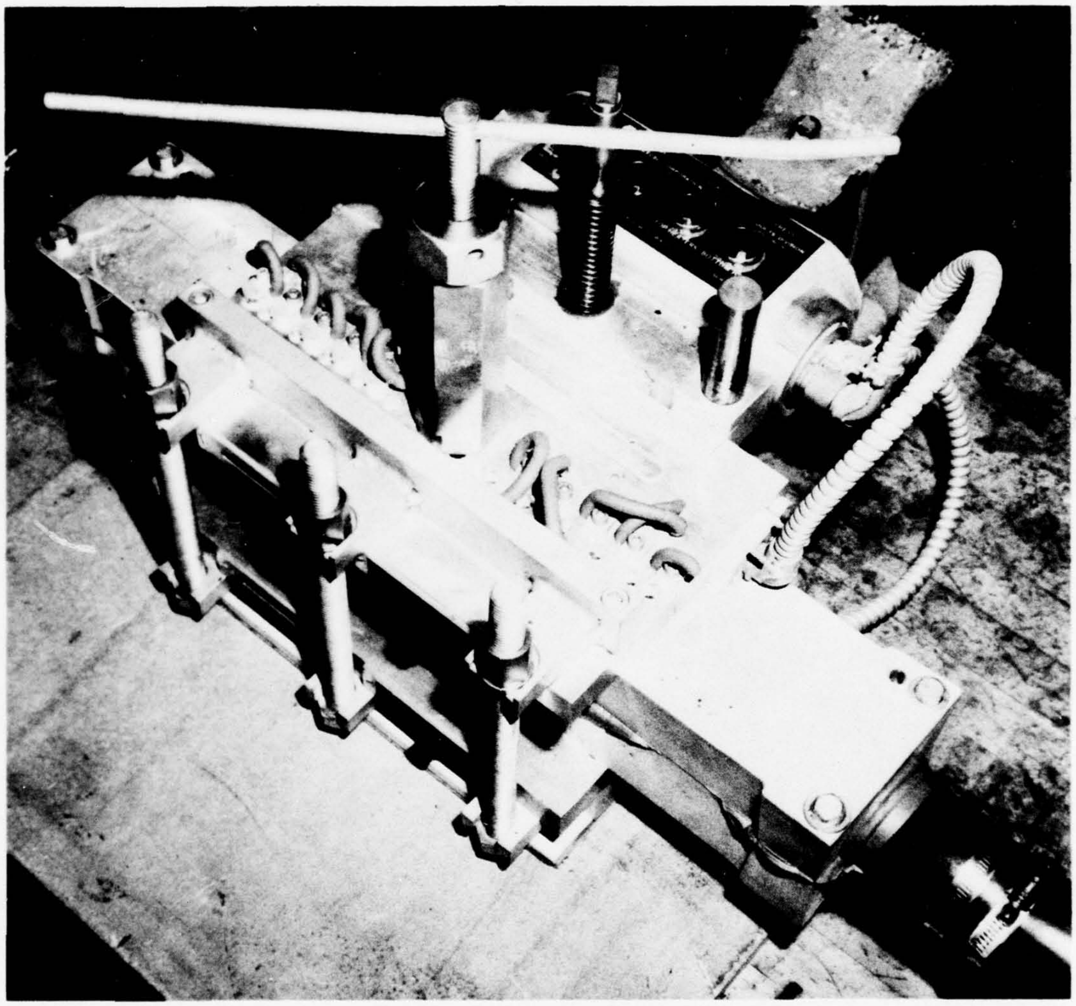


Figure 20. Press with extrusions through bleed holes.

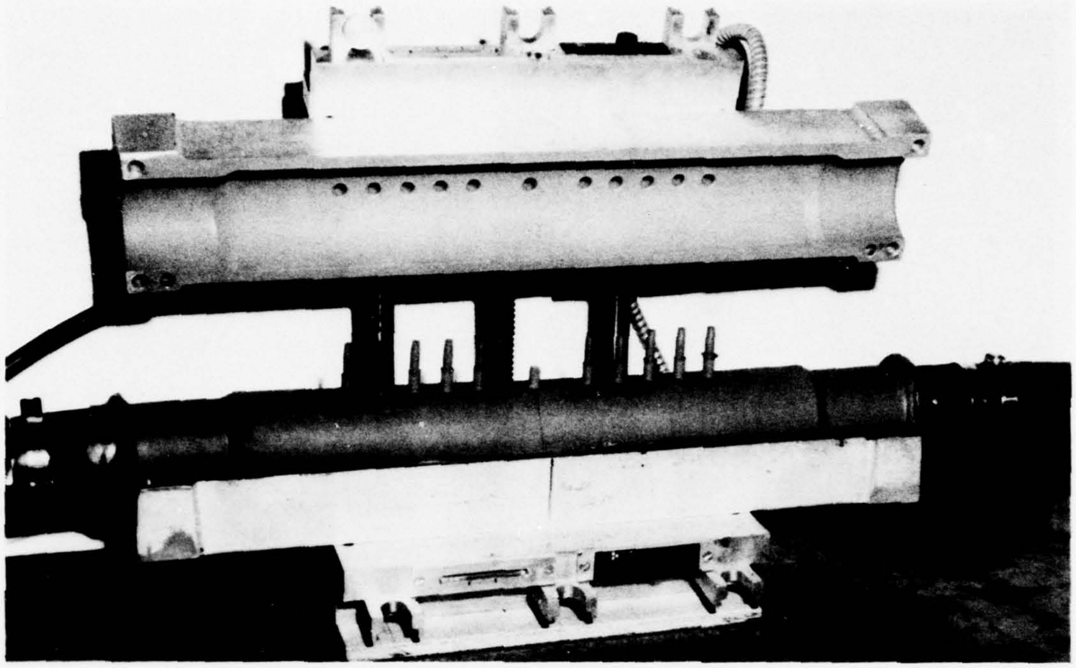


Figure 21. Vulcanized splice in opened press.

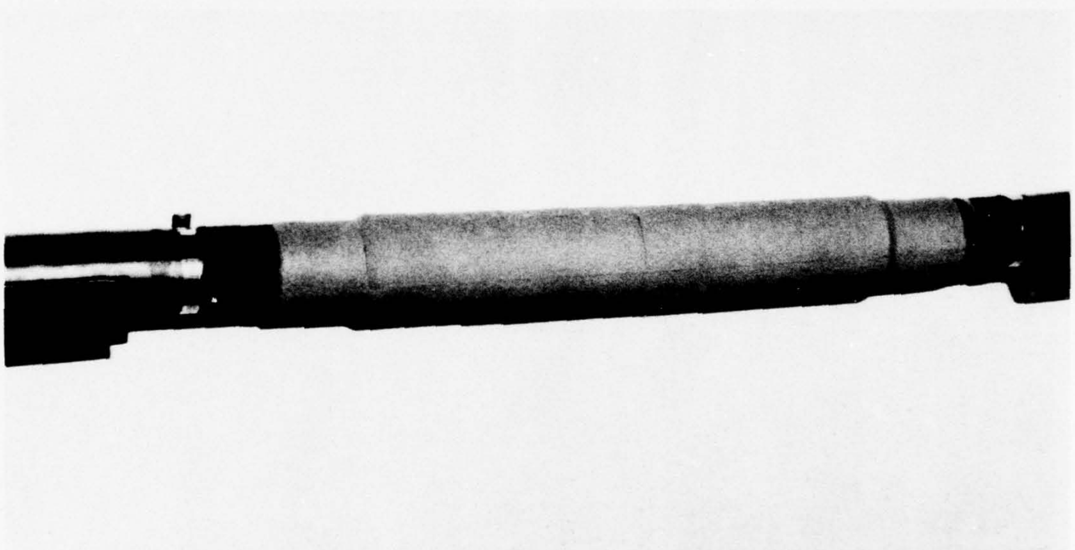


Figure 22. Finished vulcanized splice.

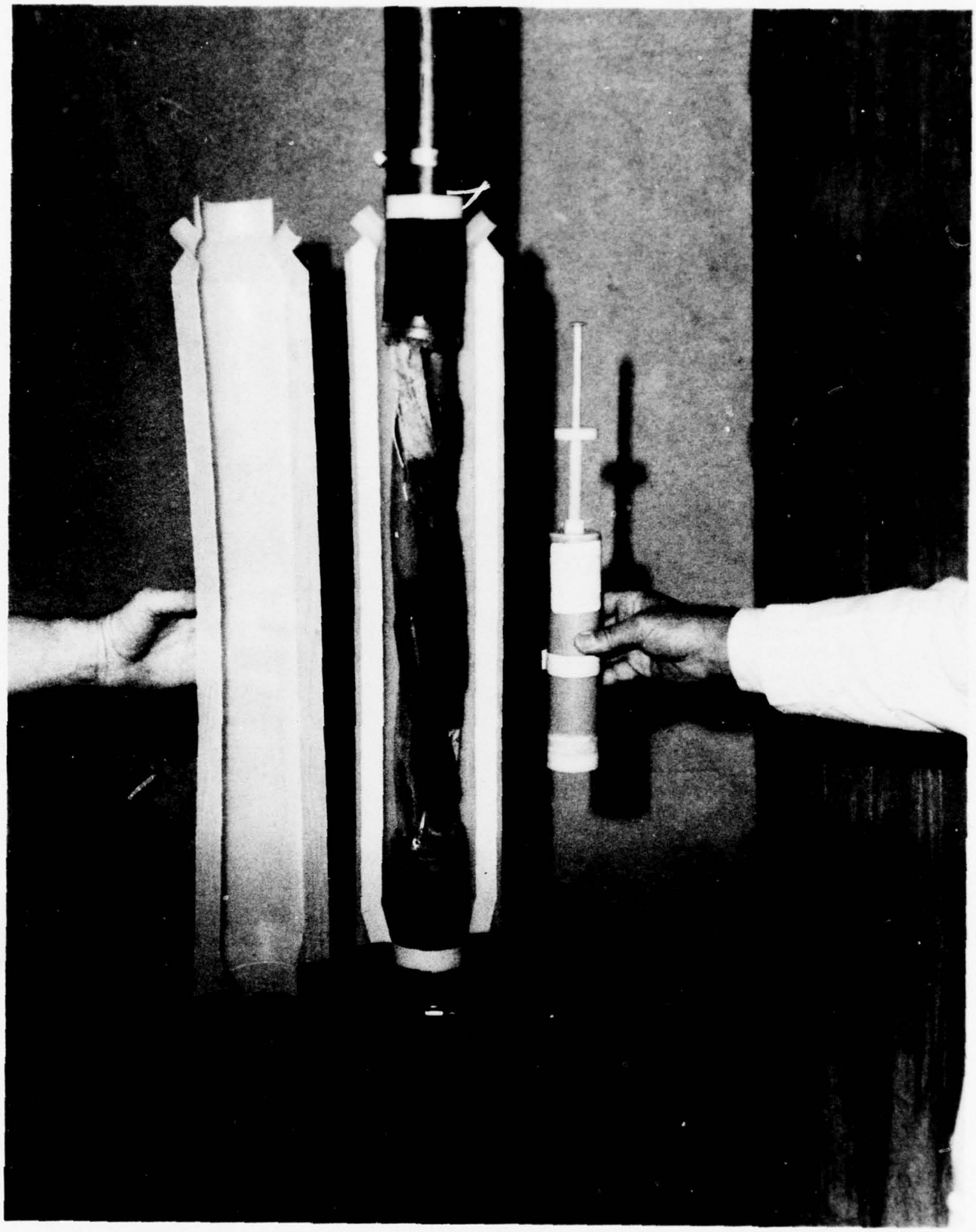


Figure 23. Preparation of ambient-temperature-cured splice cover, showing mold partially attached and view of Semkit.

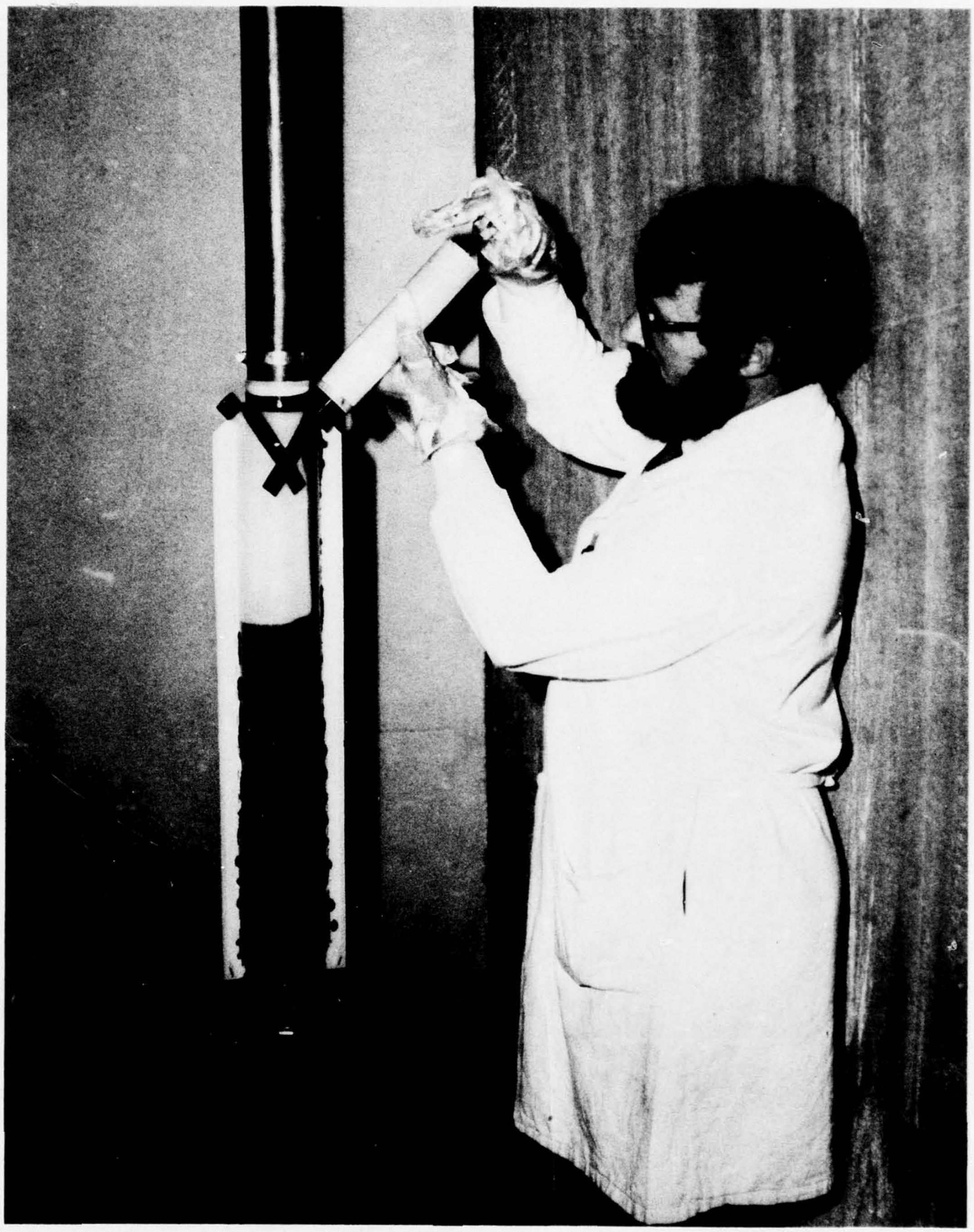


Figure 24. Injection of polyurethane mixture into mold.

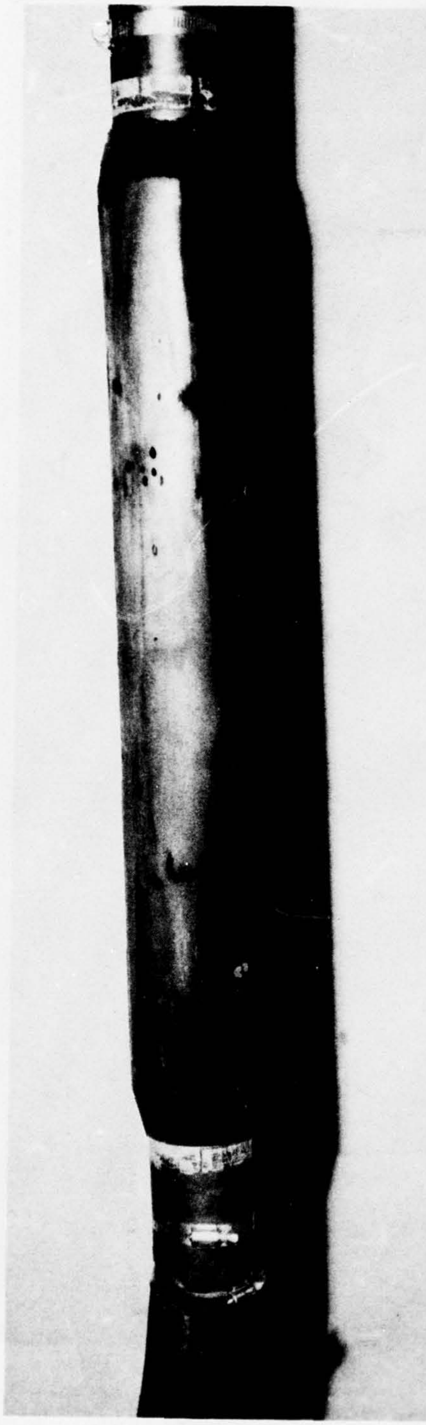


Figure 25. Finished ambient-temperature-cured splice.

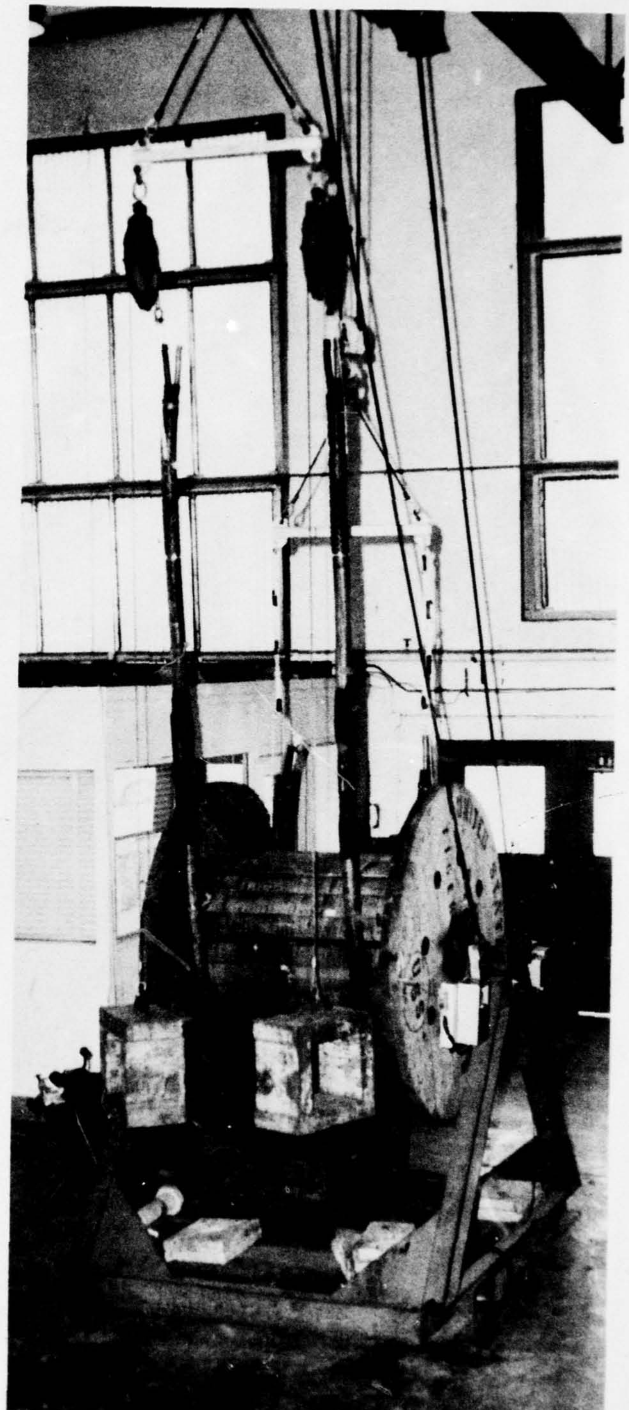


Figure 26. Cable flexing.

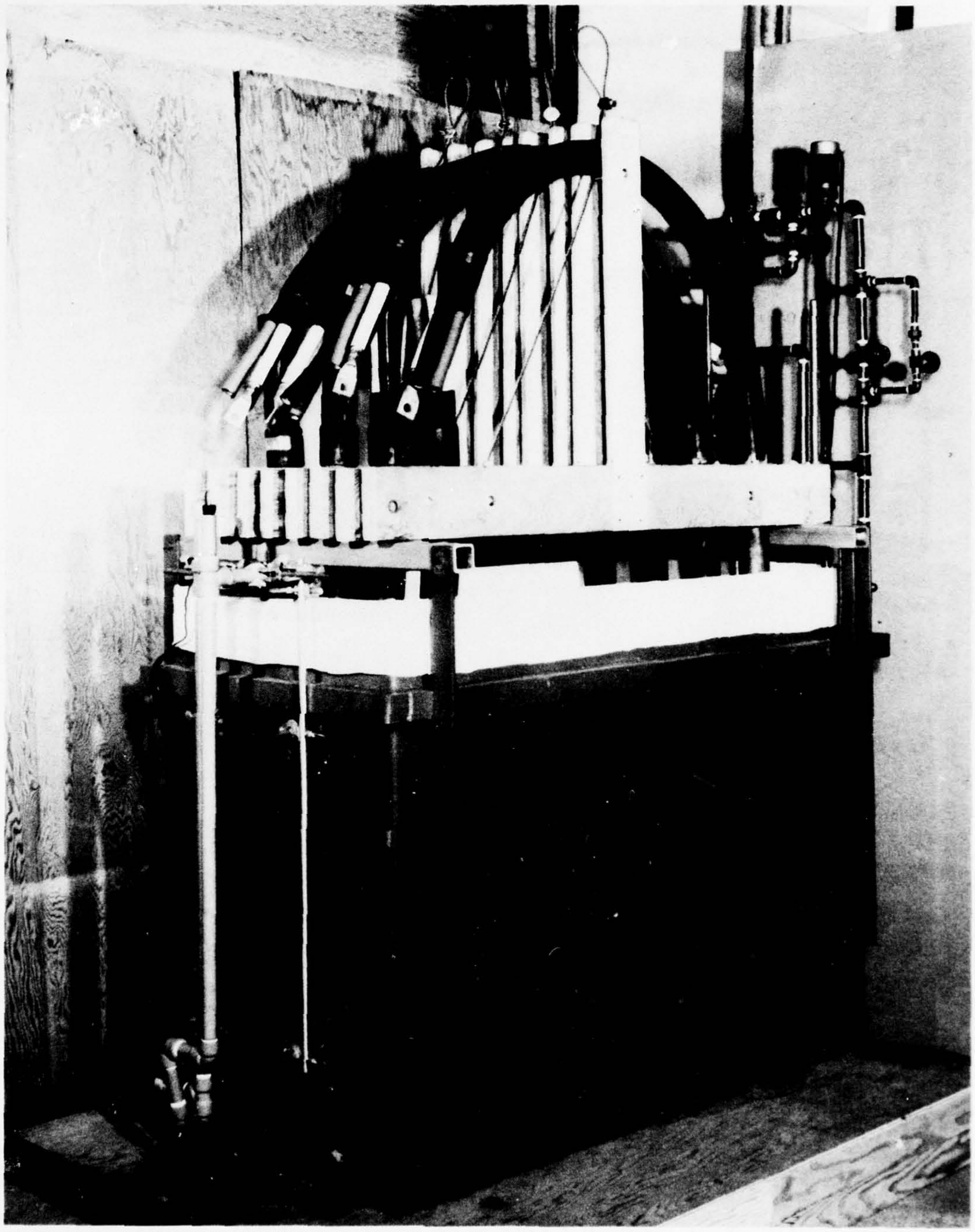


Figure 27. Water immersion bath.

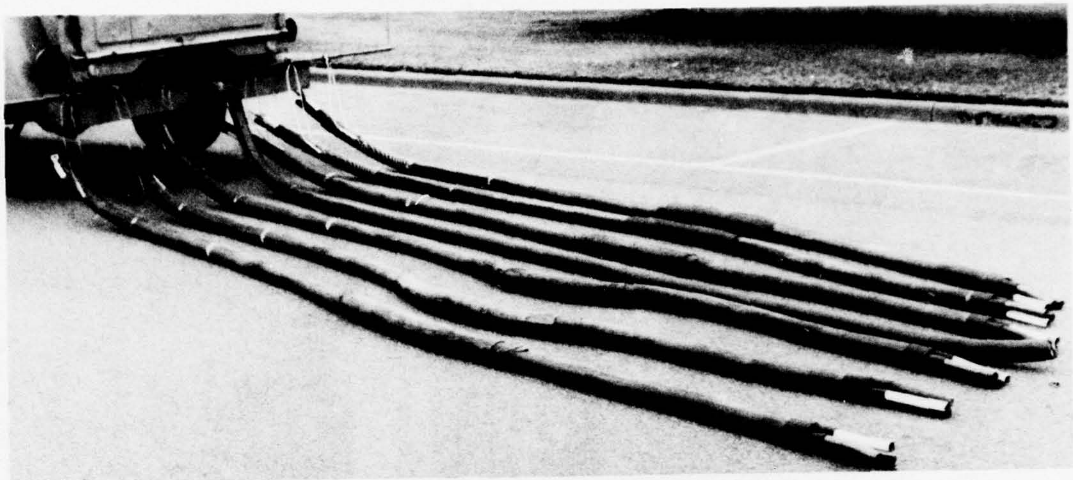


Figure 28. Abrasion test.

Figure 29. Abrasion test results after one lap.

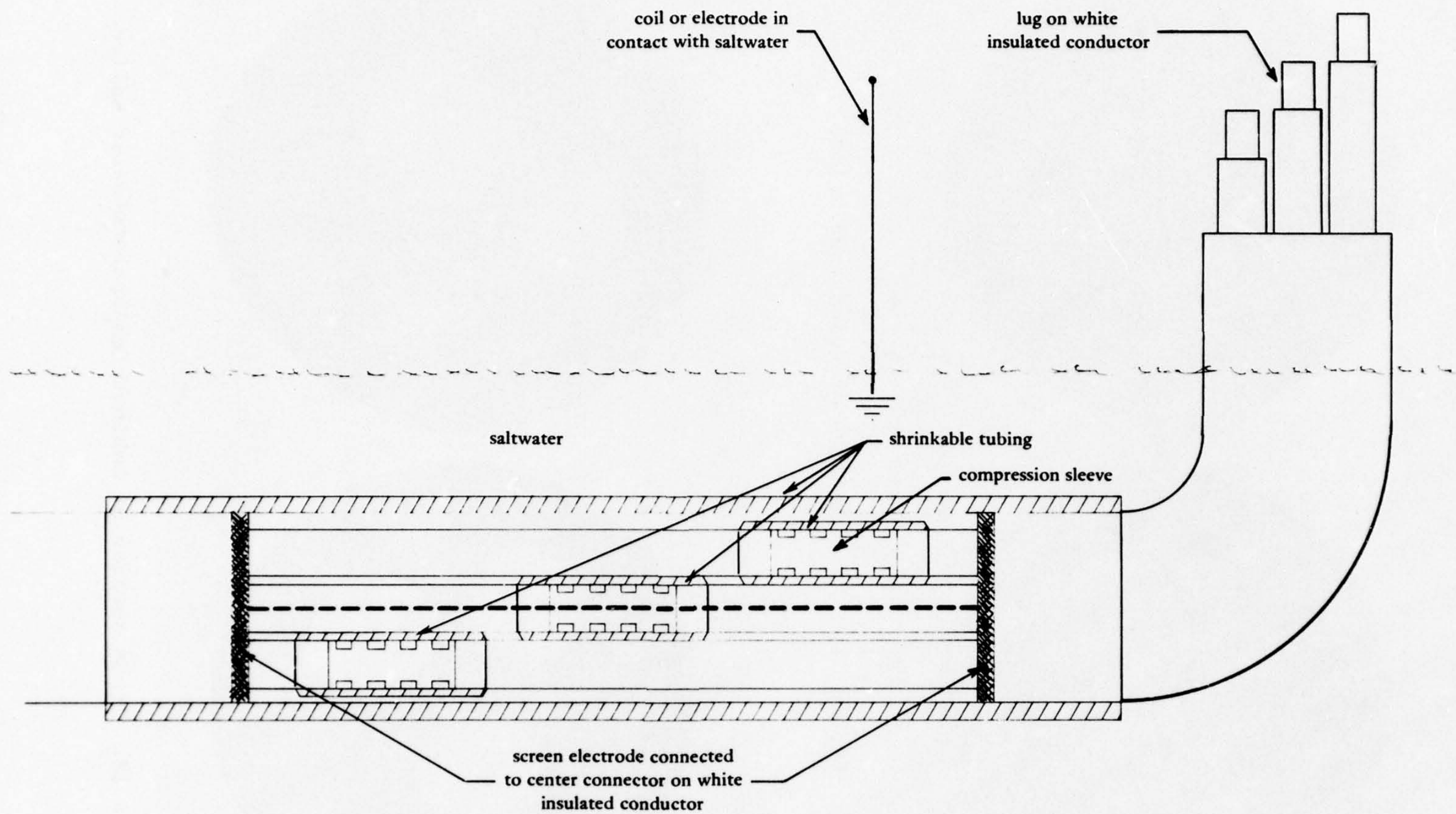


Figure 30. Schematic of splice section in bath.

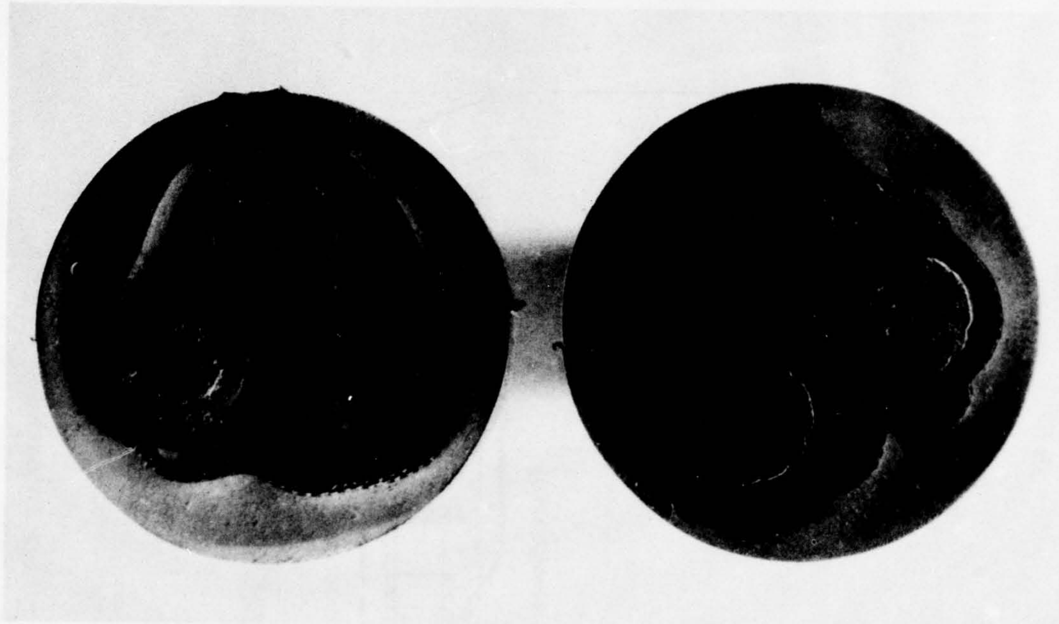


Figure 31. Cross section of vulcanized splice.

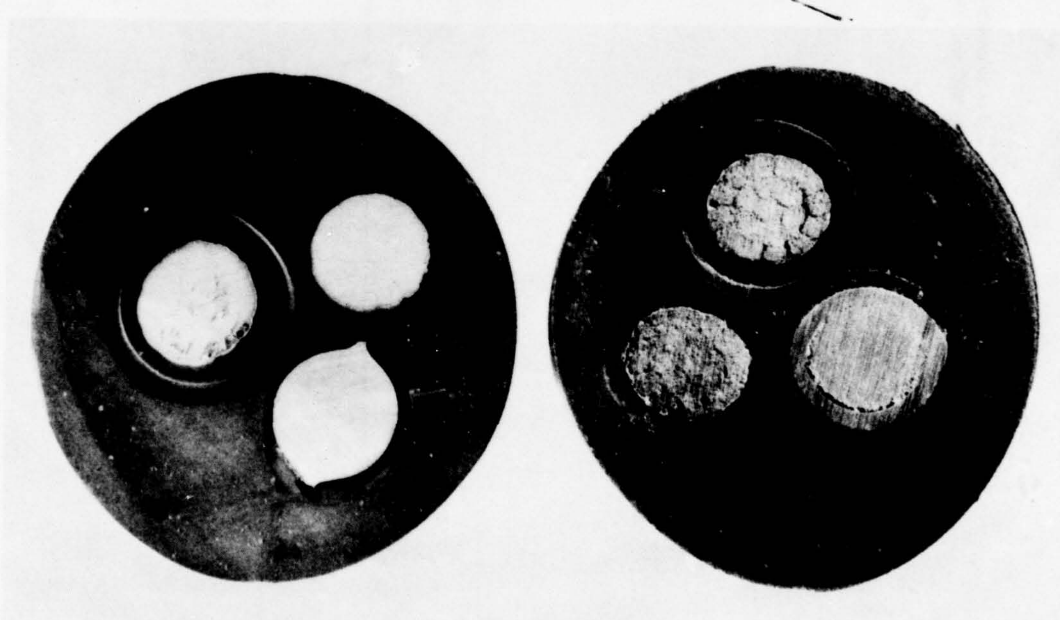
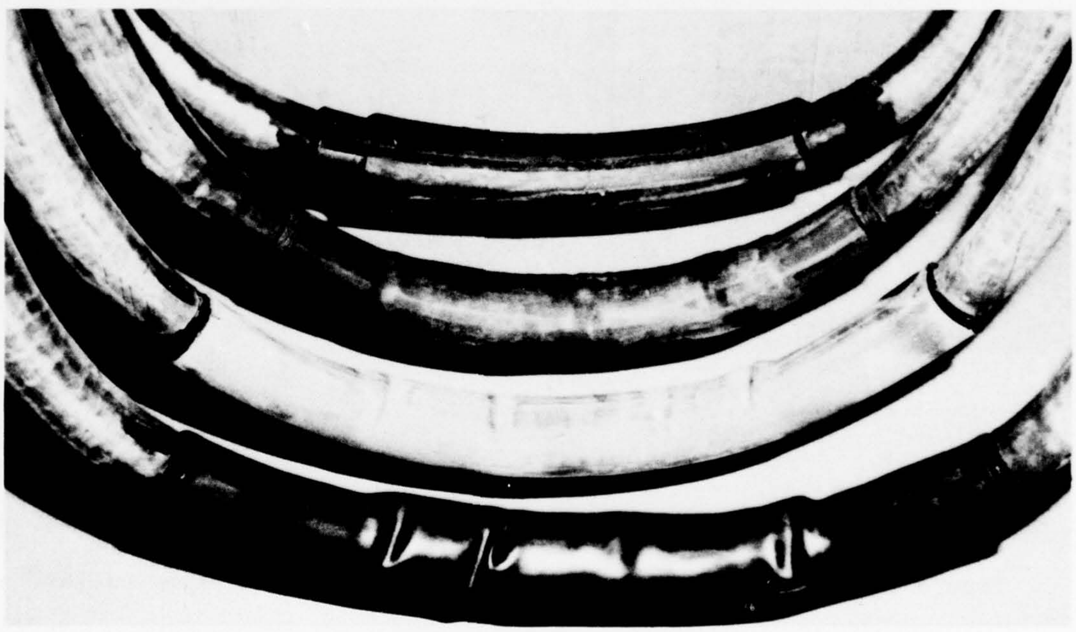


Figure 32. Cross section of ambient-temperature-cured splice.

(a) End view.



(b) Side view.

Figure 33. Sigmaform, ECC, Raychem, and Dixon splices after final flexing cycles, left to right.

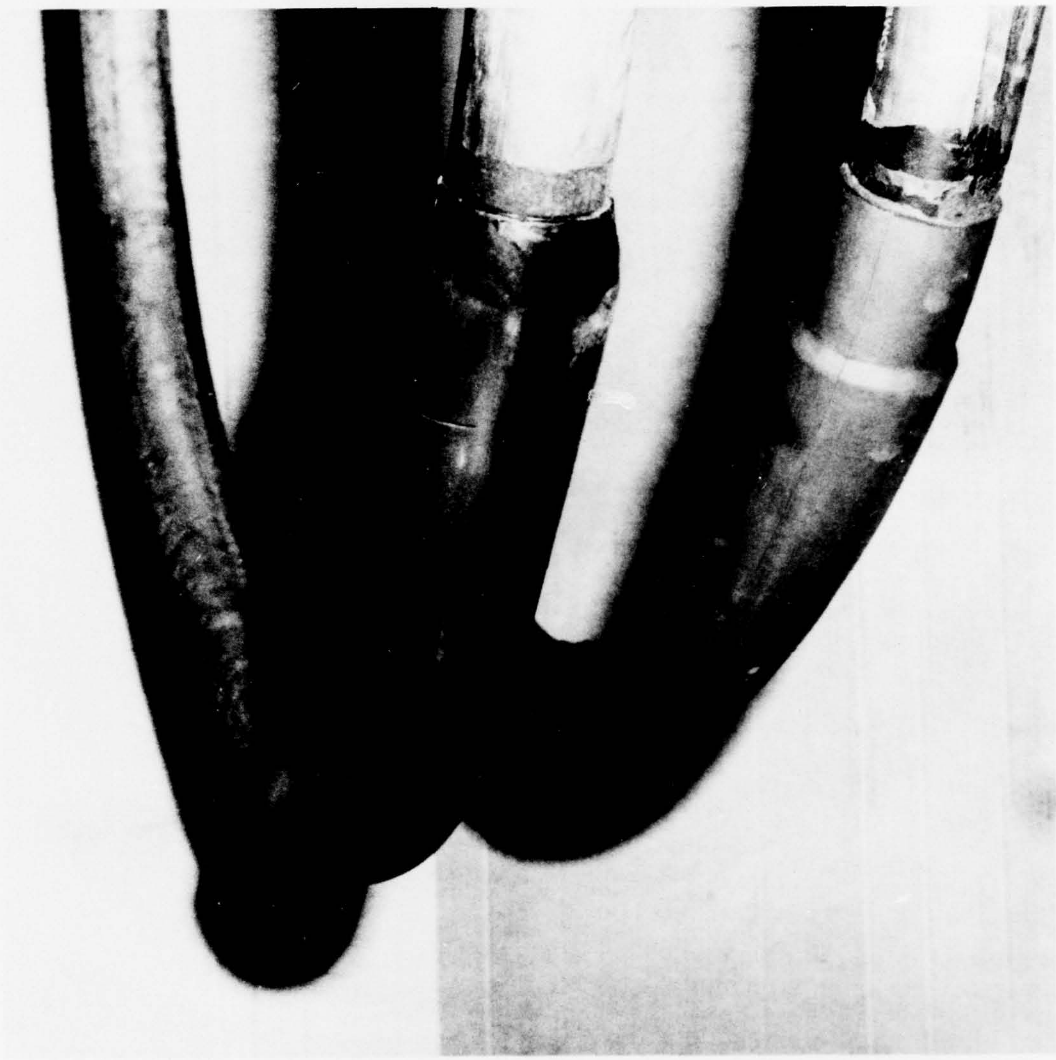


Figure 34. PRC and Hotsplicer splices after final flexing cycles.

Table 1. Electrical Measurements at the Interface of the Splice Cover and Cable Jacket

Prior Test or Exposure	Measurement[b]	Electrical Measurement Results for the Splice Noted[a]											
		Sigmaform		ECC		Raychem		Dixon		Hotsplicer		PRC	
		SS-1[c]	SS-5	SS-2	SS-6	SS-3	SS-7	SS-4	SS-8	SS-9	SS-10	SS-11	SS-12
Overnight Immersion	IR	5.8MΩ	5.4MΩ	37.0MΩ	22.0MΩ	28.0MΩ	22.0MΩ	~5kΩ	1.5kΩ	19.2MΩ	21.3MΩ	31.2MΩ	33.3MΩ
100 Flexing Cycles (250 lb)	IR	1.7MΩ	2.9MΩ	9.5MΩ	8.4MΩ	6.9MΩ	16.6MΩ	~5kΩ	1.6kΩ	18.2MΩ	17.2MΩ	30.3MΩ	40.0MΩ
200 Flexing Cycles (250 lb)	IR	1.3MΩ	2.2MΩ	8.3MΩ	5.6MΩ	5.5MΩ	10.0MΩ	~1kΩ	1.2kΩ	18.2MΩ	19.2MΩ	27.0MΩ	34.5MΩ
	VW	–	•	–	•	–	•	–	–	•	•	•	•
Immersion Heat Cycling													
1 Day	IR	345kΩ	455kΩ	1.4MΩ	2.2MΩ	1.1MΩ	2.2MΩ	–	0.8kΩ	7.8MΩ	8.0MΩ	10.9MΩ	11.1MΩ
3 Days	IR	263kΩ	286kΩ	625kΩ	715kΩ	455kΩ	715kΩ	–	0.5kΩ	8.3MΩ	8.7MΩ	8.3MΩ	6.5MΩ
5 Days	*d*	713kΩ	667kΩ	800kΩ	1.0MΩ	667kΩ	1.7MΩ	–	0.8kΩ	0.73MΩ	0.83MΩ	<0.04MΩ	<0.04MΩ
5 Days	IR	210kΩ	200kΩ	280kΩ	400kΩ	215kΩ	526kΩ	–	0.8kΩ	9.3MΩ	9.4MΩ	8.7MΩ	0.03MΩ
5 Days	VW	(960V)	(1,000V)	(1,250V)	(1,700V)	(1,000V)	•	(<10V)	–	•	•	•	(50V)
200 Flexing Cycles (500 lb)	IR	500kΩ	588kΩ	385kΩ	417kΩ	295kΩ	625kΩ	<1kΩ	1.3kΩ	12.5MΩ	13.2MΩ	12.2MΩ	8.6kΩ
	VW	–	•	–	•	–	•	–	–	–	–	–	–
Immersion Heat Cycling													
1 Day	IR	250kΩ	200kΩ	270kΩ	286kΩ	200kΩ	500kΩ	<1kΩ	0.7kΩ	6.3MΩ	6.6MΩ	4.7MΩ	8.6kΩ
3 Days	IR	233kΩ	161kΩ	208kΩ	167kΩ	156kΩ	278kΩ	–	0.9kΩ	10.0MΩ	10.2MΩ	7.8MΩ	14.3kΩ
5 Days	*d*	833kΩ	–	385kΩ	–	278kΩ	–	–	0.8kΩ	0.63MΩ	0.77MΩ	0.03MΩ	12.5kΩ
5 Days	IR	208kΩ	147kΩ	147kΩ	122kΩ	107kΩ	222kΩ	–	0.6kΩ	10.0MΩ	10.8MΩ	7.5MΩ	9.3kΩ
5 Days	VW	(900V)	(800V)	(700V)	(700V)	(500V)	(1,000V)	(~0V)	–	•	•	•	(60V)
200 Flexing Cycles (500 lb)	IR	625kΩ	455kΩ	400kΩ	233kΩ	250kΩ	278kΩ	~1kΩ	1.1kΩ	11.1MΩ	11.4MΩ	6.7MΩ	2.0kΩ
	VW	•	(2,000V)	(1,700V)	(1,100V)	(1,000V)	(1,300V)	(~0V)	–	•	•	•	(60V)

(continued)

Table 1. Continued

[a]The measurements are from the white insulated conductors to the saltwater bath; high insulation was maintained throughout the experiments for the red or black insulated conductors.

[b] IR = insulation resistance; given in megohms (MΩ) or kilohms (kΩ); a dash indicated that no measurement was made because the value was very low.

VW = voltage withstand test results; an asterisk indicates less than 5 mA current at 2,200 VAC; numbers in parentheses indicate the voltage that produced 5 mA current; a dash indicates no measurement was made.

[c]Designation for shore-to-ship splice sample.

[d]Insulation resistance measured at the end of the fifth heating period with the bath at 80C.

Table 2. Abrasion of Splices

Splice	Abrasion Depth (mils)[a]	
	0.2-Mile Course	2-Mile Course
Unspliced cable	50	150
Sigmaform (SS-5)[b]	160	-
ECC (SS-6)	160	-
Raychem (SS-7)	160	-
Dixon (SS-8)	110	200
Hotsplicer (SS-9)	70	235
PRC (SS-11)	120	290

[a]Approximate depth after dragging over asphaltic concrete a distance of 0.3 km and 3.0 km.

[b]Designation for shore-to-ship splice sample.

Table 3. Approximate Splice Costs

Basis for Cost	Sigmaform	ECC	Raychem	Hotsplicer	PRC
Basic Splice					
Materials ($)	16	11	22	22	22
Man-hours	3.5	3.5	3.5	3.5	3.5
Splice Cover					
Materials ($)	30	18	44	33	56
Man-hours	1.5	1.5	1.5	4.0	3.5
Complete Splice					
Materials ($)	46	29	66	55	78
Man-hours	5.0	5.0	5.0	7.5	7.0

Appendix

SPLICING PROCEDURES* FOR THOF-400 FLEXIBLE POWER CABLE WITH SHRINKABLE SLEEVES

1. Cut Back Cable Jacket (note section 6 on Vulcanized Splice Cover if appropriate)

   (a) For an 18-in. splice, place a hose clamp 14 in. from the end of each cable; cut back cable jacket to the clamp; remove filler (check to make sure that color coding of conductors corresponds on the two cables).

   (b) Remove any marking tape to about 1 in. from the cable jacket.

2. Mark and Cut Conductors

   (a) Clamp straightened insulated inner conductors with a perpendicular hose clamp placed 13 in. from the cable jacket (outer); place a second hose clamp about 6 in. from the cable jacket (inner).

   (b) Mark the black conductor at 0 in. and 1-3/8 in. from the outer hose clamp.

   (c) Mark the white conductor at 4 in. and 5-3/8 in. from the outer hose clamp.

   (d) Mark the red conductor at 8 in. and 9-3/8 in. from the outer hose clamp.

   (e) On second cable do the same but in the order: red, white, black.

   (f) Cut conductors at 0-, 4-, and 8-in. marks.

   (g) Cut back insulation at 1-3/8-, 5-3/8-, and 9-3/8-in. marks; hold conductor wires together with rubber bands.

3. Attach Compression Sleeves

   (a) On the three compression sleeves (or connectors) make lengthwise lines 180 deg apart; on one of the lines mark the points that are 1/2 in. and 1 in. on either side of the center.

   (b) Attach connectors to short conductors of each cable and to one of the white conductors: (1) assemble splice with the connectors and in proper lay; (2) extend outer lines on connectors onto the insulation; (3) mark contact points 90 deg apart from the extended lines, use single mark on one side, double mark on other side; (4) attach the three connectors, after rotating

---

*These detailed instructions are intended for English measurements. If they were converted to the S.I. system, or metric measurements, the dimensions would be changed to values that would be more easily measured in this system. For this reason, conversions are not shown.

the cable so that connector being compressed is at bottom of cable and making sure that the contact points line up; (5) while keeping the connector in this position, compress at the 1/2- and 1-in. marks.

(c) Assemble the splice with the three 7-in. heat-shrinkable inner sleeves inserted over the longest conductors.

(d) Complete compression of connectors, lining up marks with those on insulation (Note: Attach middle connector first; separate conductors with wedges before, but not during, the compressions).

4. Shrink on Inner Heat-Shrinkable Sleeves and Attach Test Braid*

(a) Clean the insulation about 3 in. on either side of the connector with trichloroethane, place marks 1-1/2 in. from the connectors.

(b) Attach a 20-in. braided* connecting wire to center compression fitting with fine wire.

(c) Shrink on inner sleeves with heat gun: (1) center each sleeve; (2) shrink center portion; (3) shrink each end, heating until there is a small but continuous extrusion of adhesive material.

(d) Twist and shape inner conductors to proper lay.

(e) Move hose clamp on cable jacket* back 3/8 in.; with double hacksaw blade, cut groove in cable jacket along the inside of the hose clamp; remove hose clamp.

(f) Attach braided* shielding over end of cable jacket and 1/8 in. beyond the groove; place holding wire over the groove; bend twisted end into the splice; solder both shields and the twisted wires to the braided connecting wire.

5. Heat-Shrinkable Splice Cover

(a) Fill the splice as described here or in section 5.(b). For 2-in.-wide dielectric compound in roll (or strip) from: (1) for one set of three 18-in. strips (or three 12-in. and three 6-in. strips), fold up a small portion of each strip along its length and roll the strip into a cylinder; (2) lay one rolled strip into each of the three grooves between the conductors; compress into the grooves; work from center to sides to exclude air; (3) take a second set of three 18-in. strips and fold them in half lengthwise; place the strips in the grooves, on top of the first set, and work them in; (4) lay a third set of three 18-in. strips over the exposed insulated conductors, thus covering them with a single thickness of dielectric compound, make the ends fit smoothly by cutting off a triangular wedge from one end of each strip and placing it at the other end of the strip; (5) work thick portions toward

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*The test braid and groove in cable jacket was added for testing only.

the single layers to provide mechanical continuity of the dielectric compound; work from center to sides; (6) cut two 2-in. strips about 8-3/4 in. long and make an additional layer extending 2 in. into the splice from the edge of the cable jacket.

(b) For 3-3/4-in.-wide dielectric compound: (1) cut three 18-1/2-in. strips; fold up a small portion of the strip along its length and roll the strip into a cylinder; (2) lay the rolled strips in grooves between conductors; compress to fill grooves; work from center to sides to exclude air; (3) cut three more 18-1/2-in. strips of dielectric compound; fold up 1 in., so that almost half of the strip is double thickness; (4) lay the single thicknesses over the conductors so that the double thicknesses lie on top of the partly filled groove; (5) work thick portions toward the single layers to provide mechanical continuity of the dielectric compound; work from center to sides; (6) at ends of splice, take off excess dielectric compound or add additional dielectric as needed; level off even with cable jacket.

(c) Starting 1/2 in. out over the cable jacket (or at the holding wire of the braided shielding), firmly wind varnished cambric one-third of the way into the splice, by half lapping; starting similarly at the other end of the splice, firmly wind varnished cambric one-third of the way into the splice; continue wrapping remainder of splice so as to contain, but not extrude, the dielectric compound.

(d) Solvent-clean the cable jacket where it will be covered by the outer sleeve and abrade with file card.

(e) Mark on cable jacket the end positions of the expanded outer sleeve; insert sleeve, center with wedges.

(f) Heat and shrink inner third of outer sleeve; heat and shrink the outer portions. (Note: Keep rolled end of the deflector close to cable; heat slowly to allow heat to penetrate to adhesive.)

6. Vulcanized Splice Cover

(Note: The following procedure applies to the Hotsplicer model 560J heavy-duty molding press with a splicing mold no. 24-325-287. Of help is a 28-in. template marked for a 26-in. application of the uncured neoprene and for a tapering to an 18-in. mold cavity. For the vulcanized splice make the changes in the prior sections that are listed below and add the following statement to section 2.f: "before cutting at the 7-in. mark, remove any exposed marking tape").

Section	Change From (in.)	To (in.)
1.a	18	16
	14	12-1/2
1.b	1	1/2
2.a	13	11-1/2
	6	5-1/2
2.c	4	3-1/2
	5-3/8	4-7/8
2.d	8	7
	9-3/8	8-3/8
2.f	4	3-1/2
	8	7
2.g	5-3/8	4-7/8
	9-3/8	8-3/8
3.c	7	6

(a) Place cable supports 32 in. apart and put hose clamps on outer insulation 14-1/8 in. from the center of the splice.

(b) Untwist the splice to provide space between conductors; coat shrinkable sleeves and 2 in. of rubber insulation next to sleeves with #601 bonding agent; let dry 15 min.

(c) Clean cable jacket with trichloroethane out 5 in. from splice; buff with #80 aloxite cloth until all shiny surfaces are removed; coat with #601 bonding agent.

(d) Wrap single width but double thicknesses of #203 unvulcanized gray insulating tape (about an 8-in. strip) on rubber insulation at each end of shrinkable sleeves; place a 3-in., double-thickness piece of #102 unvulcanized green neoprene tape behind each of the two shortest conductors; twist splice back into proper lay.

(e) Remove plug from press and open bleed hole covers by turning clockwise; clean the mold and wipe it with detergent solution; preheat the press to 225F (while continuing the splice preparation).

(f) Prepare three sets of four 16-in. pieces of #102 neoprene tape laid on top of each other; place them in the grooves between the three conductors; hold them with #225 nylon-reinforced neoprene binding tape; half-lap #225 binding tape the full length between the cable jackets.

(g) Wrap the splice with #102 neoprene tape by half-lapping: (1) wrap center of splice to thickness of cable jacket; (2) wrap full length of splice as shown by the template, being sure there is neat half-lapping (and therefore a double layer) over the cable jacket; (3) build middle of splice up evenly, tapering as shown by the template, to a minimum diameter of 3-1/4 in. as measured by outside calipers, but do not overwrap.

(h) With hose clamps 15 in. from center of splice, attach 30-in. nylon webbing to each outer jacket, folding end in a "figure 6" to provide a double layer under hose clamp.

(i) Cut five 18-in. strips of #102 neoprene tape, place three strips side-by-side, cover the joints with the other two strips, place composite strip in bottom of mold; place splice into mold, centering carefully; just barely close the mold, using the crank and the center bolt at the front; insert the four bolts and washers at the ends of the molds; attach transfer pot with four 22-in. coils of #102 neoprene tape onto top platen.

(j) Place tension anchors over cable; attach nylon straps; with nuts loosened, fasten tension anchors as far out as possible; place 4-in. blocks under cable; adjust tension to 250 lb keeping splice centered in mold; close the mold evenly and tightly with the bolts already in place; attach the remaining two bolts at the front of the press.

(k) Transfer neoprene from transfer pot to mold; when extrusions reach 2 in., close bleed holes, keeping Allen-head screws snug and then tightening; when ends of mold are completely filled, as shown by extrusions, remove transfer pot and insert plug.

(l) Increase mold temperature to 325F.

(m) Hold at 325F for 70 min; turn off heaters.

(n) Allow press to cool to 175F before removing splice; if splice has cooled to room temperature, reheat press to 150F before removing splice.

(o) When splice is cool, trim flashing at body of splice and uncured neoprene at ends of splice.

7. Ambient-Temperature-Cured Splice Cover

(a) Place cable supports at least 33 in. apart and put hose clamps on outer insulation 14-3/4 in. from center of splice.

(b) Untwist splice to provide space between conductors; clean shrinkable sleeves and adjacent 2 in. of insulation (but not extruded adhesive) with trichloroethane; wipe shrinkable

sleeves and adjacent insulation with PR 143 cleaner on gauze pad; wipe off excess PR 143 with fresh gauze pad; twist splice back into proper lay.

(c) With second set of hose clamps 15-1/2 in. from center of splice, attach 30-in. nylon webbing strap to each outer jacket, folding in a figure 6 to provide a double layer under hose clamp; with shackles, attach one strap to hoist and other strap to 25-lb weight; raise hoist to provide tension at splice; if hose clamps originally 14-3/4 in. from center of splice are not 30 in. apart, make reference mark 30 in. from lower hose clamp.

(d) Clean cable jacket ends to within about 1 in. of hose clamps with trichloroethane; abrade cable jacket ends to within 1-3/4 in. of hose clamps (or 30-in. reference mark), using a high speed (about 25,000 rpm) hand tool and rotary file in a direction that will tend to make the file travel away from the splice, and being certain that no smooth areas remain; wipe abraded area with PR 143 cleaner on gauze pad; wipe off excess PR 143 with fresh gauze pad.

(e) Attach double layer of double adhesive masking tape around cable jacket outside of marks 2 in. inside the hose clamps (or 30-in. reference mark); apply double adhesive masking tape to flanges of one mold half, cutting in small pieces at the bottom taper of the mold.

(f) Attach mold to cable: (1) match bottom corners of mold (and ridge at bottom) and secure each corner with one staple from plier-type stapler; (2) match top corners of mold (and pouring holes) and secure with staples; (3) line up flanges, compress at masking tape, and staple inside portion of flange at the widest portion of the mold (not at tapered portion); (4) hold bottom of mold together near cable, place ridge at upper edge of masking tape, tape mold ends together with electrical tape over the area of the masking tape, finish stapling bottom of mold (at tapered portion); (5) hold top of mold together, tape mold ends onto cable, tape pouring holes to fit Semkit cartridge, complete stapling of mold; (6) cover all openings with small amount of PR-615-HF putty and with electric tape.

(g) Fill mold with PR 498-1/4 polyurethane mixture (CAUTION! Observe all safety precautions: hold bottom cap against cartridge until ready to remove); (1) from Semkit cartridge remove clinch-band, pull dasher rod back to release foil barrier from dasher, and depress cartridge in area of clinch-band to deform foil barrier; (2) push dasher rod all the way in to remove foil barrier and pull rod back all the way out, mix with 60 such in-and-out strokes (rotate dasher rod 90 deg

clockwise during each stroke, provide extra mixing at each end of the cartridge, and take no more than about 3 min); (3) with dasher positioned near middle of cartridge, insert ramrod into handle of dasher rod, break piston loose and inject contents into cartridge; (4) mix material again briskly with at least 30 strokes (in about 1 minute); (5) remove bottom cap, with dasher rod all the way out and pointing up, unscrew dasher rod; (6) insert Semkit nozzle into pouring hole of mold, extrude contents by pushing plunger in with dasher rod; (7) continue mixing Semkits and adding polyurethane mixture until mold is full.

(h) After minimum of 2 hr, remove mold; allow splice to air-dry to eliminate "after-tack"; remove flashing and plugs.

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MCAS Facil. Engr. Div. Cherry Point NC; CO, Kaneohe Bay HI; Code PWE, Kaneohe Bay HI; Code S4, Quantico VA; J. Taylor, Iwakuni Japan; PWD, Dir. Maint. Control Div., Iwakuni Japan; PWO Kaneohe Bay HI; PWO, Yuma AZ
MCRD PWO, San Diego Ca
NAVFACENGCOM CONTRACT AROICC, Quantico, VA
NAD Code 011B-1, Hawthorne NV; Engr. Dir. Hawthorne, NV; PWD Nat./Resr. Mgr Forester, McAlester OK
NAF PWO Sigonella Sicily; PWO, Atsugi Japan
NAS Asst C/S CE Corpus Christi, TX; CO, Guantanamo Bay Cuba; Code 114, Alameda CA; Code 183 (Fac. Plan BR MGR); Code 187, Jacksonville FL; Code 18700, Brunswick ME; Code 18U (ENS P.J. Hickey), Corpus Christi TX; Code 6234 (G. Trask), Point Mugu CA; Code 70, Atlanta, Marietta GA; Dir. Util. Div., Bermuda; ENS Buchholz, Pensacola, FL; PW (J. Maguire), Corpus Christi TX; PWD (M.B. Trewitt), Dallas TX; PWD Maint. Div., New Orleans, Belle Chasse LA; PWD, Maintenance Control Dir., Bermuda; PWD, Willow Grove PA; PWO Belle Chasse, LA; PWO Chase Field Beeville, TX; PWO Key West FL; PWO Whiting Fld, Milton FL; PWO, Dallas TX; PWO, Glenview IL; PWO, Kingsville TX; PWO, Millington TN; PWO, Miramar, San Diego CA; PWO., Moffett Field CA; Lakehurst, NJ; SCE Lant Fleet Norfolk, VA; SCE Norfolk, VA
NATL RESEARCH COUNCIL Naval Studies Board, Washington DC
NATNAVMEDCEN PWO Bethesda, MD
NATPARACHUTETESTRAN PW Engr, El Centro CA
NAVACT PWO, London UK
NAVAEROSPREGMEDCEN SCE, Pensacola FL
NAVAL FACILITY PWO, Barbados; PWO, Brawdy Wales UK; PWO, Cape Hatteras, Buxton NC; PWO, Centerville Bch, Ferndale CA; PWO, Guam
NAVAVIONICFAC PWD Deputy Dir. D/701, Indianapolis, IN
NAVCOASTSYSLAB Code 423 (D. Good), Panama City FL; Code 715 (J. Quirk) Panama City, FL; Library Panama City, FL

NAVCOMMAREAMSTRSTA Code W-602, Honolulu, Wahiawa HI; PWO, Norfolk VA; PWO, Wahiawa HI; SCE Unit 1 Naples Italy
NAVCOMMSTA CO (61E) Puerto Rico; CO, San Miguel, R.P.; Code 401 Nea Makri, Greece; PWO, Adak AK; PWO, Fort Amador Canal Zone
NAVCOMMUNIT Cutler/E. Machias ME (PW Gen. For.)
NAVCONSTRACEN CO (CDR C.L. Neugent), Port Hueneme, CA
NAVFAC PWO, Lewes DE
NAVFACENGCOM Code 043 Alexandria, VA; Code 044 Alexandria, VA; Code 0451 Alexandria, VA; Code 0454B Alexandria, Va; Code 04B3 Alexandria, VA; Code 04B5 Alexandria, VA; Code 101 Alexandria, VA; Code 1023 (M. Carr) Alexandria, VA; Code 1023 (T. Stevens) Alexandria, VA; Code 104 Alexandria, VA; Code 2014 (Mr. Taam), Pearl Harbor HI; P W Brewer
NAVFACENGCOM - CHES DIV. Code 101 Wash, DC; Code 402 (R. Morony) Wash, DC; Code 403 (H. DeVoe) Wash, DC; Code 405 Wash, DC; Code FPO-1SP (Dr. Lewis) Wash, DC; Code FPO-IP12 (Mr. Scola), Washington DC
NAVFACENGCOM - LANT DIV. Code 111, Norfolk, VA; LANTDIV (J.L. Dettbarn) Alexandria, VA; RDT&ELO 09P2, Norfolk VA
NAVFACENGCOM - NORTH DIV. CO; Code 1028, RDT&ELO, Philadelphia PA; Code 111 (Castranovo); Code 114 (A. Rhoads); Design Div. (R. Masino), Philadelphia PA; ROICC, Contracts, Crane IN
NAVFACENGCOM - PAC DIV. Code 402, RDT&E, Pearl Harbor HI; Commander, Pearl Harbor, HI
NAVFACENGCOM - SOUTH DIV. Code 90, RDT&ELO, Charleston SC; Dir., New Orleans LA
NAVFACENGCOM - WEST DIV. 102; 112; AROICC, Contracts, Twentynine Palms CA; Code 04B; O9P/20; RDT&ELO Code 2011 San Bruno, CA
NAVFACENGCOM CONTRACT AROICC, Point Mugu CA; Code 05, TRIDENT, Bremerton WA; Dir, Eng. Div., Exmouth, Australia; Eng Div dir, Southwest Pac, Manila, PI; OICC, Southwest Pac, Manila, PI; OICC/ROICC, Balboa Canal Zone; ROICC LANT DIV., Norfolk VA; ROICC Off Point Mugu, CA; ROICC, Clark AFB, PI; ROICC, Pacific, San Bruno CA
NAVHOSP LT R. Elsbernd, Puerto Rico
NAVNUPWRU MUSE DET OIC, Port Hueneme CA
NAVOCEANSYSCEN Code 6565 (Tech. Lib.), San Diego CA; Code 6700, San Diego, CA; Code 7511 (PWO) San Diego, CA; SCE (Code 6600), San Diego CA
NAVORDSTA PWO, Louisville KY
NAVPETOFF Code 30, Alexandria VA
NAVPHIBASE CO, ACB 2 Norfolk, VA
NAVRADRECFAC PWO, Kami Seya Japan
NAVREGMEDCEN PWO Newport RI; PWO Portsmouth, VA; SCE (LCDR B. E. Thurston), San Diego CA; SCE, Guam
NAVSCOLCECOFF C35 Port Hueneme, CA; CO, Code C44A Port Hueneme, CA
NAVSECGRUACT PWO, Edzell Scotland; PWO, Puerto Rico; PWO, Torri Sta, Okinawa
NAVSHIPYD CO Marine Barracks, Norfolk, Portsmouth VA; Code 202.4, Long Beach CA; Code 202.5 (Library) Puget Sound, Bremerton WA; Code 400, Puget Sound; Code 400.03 Long Beach, CA; Code 404 (LT J. Riccio), Norfolk, Portsmouth VA; Code 410, Mare Is., Vallejo CA; Code 440 Portsmouth NH; Code 440, Norfolk; Code 440, Puget Sound, Bremerton WA; Code 440.4, Charleston SC; Code 450, Charleston SC; Code 453 (Util. Supr), Vallejo CA; L.D. Vivian; Library, Portsmouth NH; PWD (Code 400), Philadelphia PA; PWD (LT N.B. Hall), Long Beach CA; PWO, Mare Is.; PWO, Puget Sound; SCE, Pearl Harbor HI
NAVSTA CO Naval Station, Mayport FL; CO Roosevelt Roads P.R. Puerto Rico; Engr. Dir., Rota Spain; Maint. Cont. Div., Guantanamo Bay Cuba; Maint. Div. Dir/Code 531, Rodman Canal Zone; PWO Midway Island; PWO, Keflavik Iceland; PWO, Mayport FL; PWO, Puerto Rico; ROICC, Rota Spain; SCE, Guam; SCE, San Diego CA; SCE, Subic Bay, R.P.; Utilities Engr Off. (LTJG A.S. Ritchie), Rota Spain
NAVSUBASE SCE, Pearl Harbor HI
NAVSUPPACT CO, Brooklyn NY; CO, Seattle WA; Code 4, 12 Marine Corps Dist, Treasure Is., San Francisco CA; LTJG McGarrah, Vallejo CA; Plan/Engr Div., Naples Italy
NAVSURFWPNCEN PWO, White Oak, Silver Spring, MD
NAVTECHTRACEN SCE, Pensacola FL
NAVWPNCEN Code 2636 (W. Bonner), China Lake CA; PWO (Code 26), China Lake CA; ROICC (Code 702), China Lake CA
NAVWPNSTA Code 092A (C. Fredericks) Seal Beach CA; ENS G.A. Lowry, Fallbrook CA; Maint. Control Dir., Yorktown VA; PW Office (Code 09C1) Yorktown, VA; PWO Yorktown, VA
NAVWPNSUPPCEN Code 09 (Boennighausen) Crane IN

PWC Code 40 (C. Kolton) Pensacola, FL
NAVEDTRAPRODEVCEN Tech. Library
NAVFACENGCOM - LANT DIV. Eur. BR Deputy Dir, Naples Italy
NAVSHIPREPFAC SCE Subic Bay
NAVSUBASE ENS S. Dove, Groton, CT; LTJG D.W. Peck, Groton, CT
WPNSTA EARLE Code 092, Colts Neck NJ
NCBC CEL (CAPT N. W. Petersen), Port Hueneme, CA; CEL AOIC Port Hueneme CA; Code 10 Davisville, RI; Code 400, Gulfport MS; PW Engrg, Gulfport MS; PWO (Code 80) Port Hueneme, CA; PWO, Davisville RI
NCBU 411 OIC, Norfolk VA
NCR 20, Commander
NMCB 5, Operations Dept.; Forty, CO; THREE, Operations Off.
NROTCU Univ Colorado (LT D R Burns), Boulder CO
NSC Code 54.1 (Wynne), Norfolk VA
NSD SCE, Subic Bay, R.P.
NTC Commander Orlando, FL; SCE Great Lakes, IL
NUSC Code 131 New London, CT; Code EA123 (R.S. Munn), New London CT
OCEANSYSLANT LT A.R. Giancola, Norfolk VA
OFFICE SECRETARY OF DEFENSE OASD (I&L) Pentagon (T. Casberg), Washington DC
NORDA Code 440 (Ocean Rsch. off) Bay St. Louis, Ms
ONR Code 700F Arlington VA
PMTC Pat. Counsel, Point Mugu CA
PWC ENS J.E. Surash, Pearl Harbor HI; ACE Office (LTJG St. Germain) Norfolk VA; CO, Great Lakes IL; Code 116 (LTJG. A. Eckhart) Great Lakes, IL; Code 120, Oakland CA; Code 120C (Library) San Diego, CA; Code 128, Guam; Code 200, Great Lakes IL; Code 200, Oakland CA; Code 220 Oakland, CA; Code 220.1, Norfolk VA; Code 30C (Boettcher) San Diego, CA; Code 505A (H. Wheeler); Code 680, San Diego CA; OIC CBU-405, San Diego CA; XO Oakland, CA
SPCC Code 122B, Mechanicsburg, PA; PWO (Code 120) Mechanicsburg PA
U.S. MERCHANT MARINE ACADEMY Kings Point, NY (Reprint Custodian)
USCG (G-ECV/61) (Burkhart) Washington, DC; G-EOE-4/61 (T. Dowd), Washington DC
USCG ACADEMY LT N. Stramandi, New London CT
USNA Ch. Mech. Engr. Dept Annapolis MD; PWD Engr. Div. (C. Bradford) Annapolis MD
CORNELL UNIVERSITY Ithaca NY (Serials Dept, Engr Lib.)
DAMES & MOORE LIBRARY LOS ANGELES, CA
ILLINOIS STATE GEO. SURVEY Urbana IL
LEHIGH UNIVERSITY Bethlehem PA (Linderman Lib. No.30, Flecksteiner)
LIBRARY OF CONGRESS WASHINGTON, DC (SCIENCES & TECH DIV)
MIT Cambridge MA; Cambridge MA (Rm 10-500, Tech. Reports, Engr. Lib.)
NY CITY COMMUNITY COLLEGE BROOKLYN, NY (LIBRARY)
PURDUE UNIVERSITY Lafayette, IN (CE Engr. Lib)
CONNECTICUT Hartford CT (Dept of Plan. & Energy Policy)
UNIVERSITY OF CALIFORNIA BERKELEY, CA (OFF. BUS. AND FINANCE, SAUNDERS); Berkeley CA (E. Pearson)
UNIVERSITY OF DELAWARE Newark, DE (Dept of Civil Engineering, Chesson)
UNIVERSITY OF ILLINOIS URBANA, IL (LIBRARY)
UNIVERSITY OF MASSACHUSETTS (Heronemus), Amherst MA CE Dept
UNIVERSITY OF NEBRASKA-LINCOLN Lincoln, NE (Ross Ice Shelf Proj.)
UNIVERSITY OF TEXAS Inst. Marine Sci (Library), Port Arkansas TX
UNIVERSITY OF WISCONSIN Milwaukee WI (Ctr of Great Lakes Studies)
URS RESEARCH CO. LIBRARY SAN MATEO, CA
BECHTEL CORP. SAN FRANCISCO, CA (PHELPS)
COLUMBIA GULF TRANSMISSION CO. HOUSTON, TX (ENG. LIB.)
DURLACH, O'NEAL, JENKINS & ASSOC. Columbia SC
FORD, BACON & DAVIS, INC. New York (Library)
GLIDDEN CO. STRONGSVILLE, OH (RSCH LIB)
LOCKHEED MISSILES & SPACE CO. INC. Sunnyvale, CA (Phillips)
MCDONNEL AIRCRAFT CO. Dept 501 (R.H. Fayman), St Louis MO
OCEAN DATA SYSTEMS, INC. SAN DIEGO, CA (SNODGRASS)
RAYMOND INTERNATIONAL INC. CHERRY HILL, NJ (SOILTECH DEPT)

SHELL DEVELOPMENT CO. HOUSTON,, TX (TELES)
WISS, JÁNNEY, ELSTNER, & ASSOC Northbrook, IL (J. Hanson)
WOODWARD-CLYDE CONSULTANTS PLYMOUTH MEETING PA (CROSS, III)
BRAHTZ La Jolla, CA
BRYANT ROSE Johnson Div. UOP, Glendora CA
GREG PAGE EUGENE, OR
R.F. BESIER Old Saybrook CT
T.W. MERMEL Washington DC